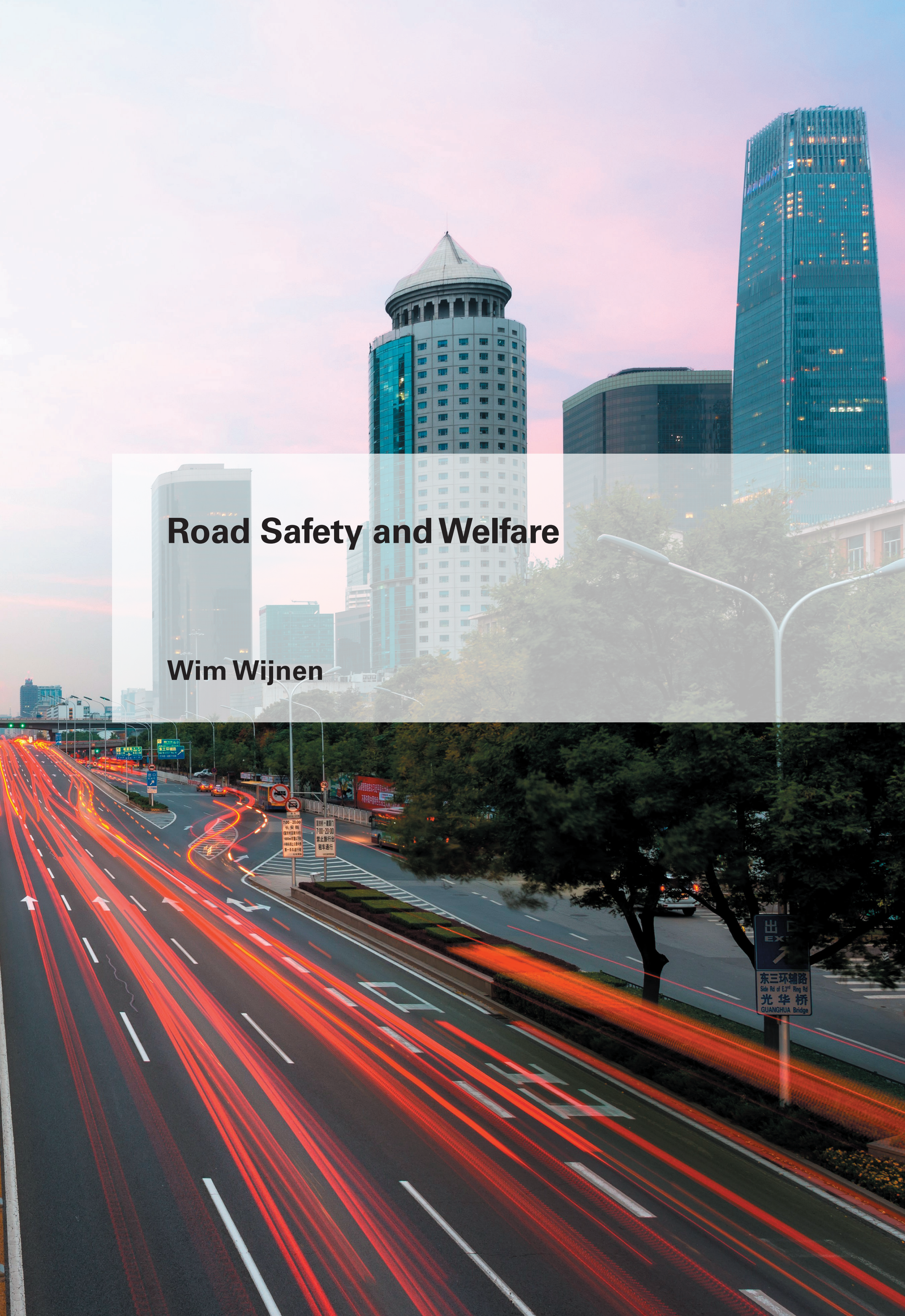
Road Safety and Welfare

Wim Wijnen



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1. Introduction

1.1. Road safety and economic assessment

Road crashes are a worldwide societal problem. The annual number of road fatalities is estimated at 1.19 million in 2021 (WHO, 2023) and the annual number of injured road casualties at 20 to 50 million (WHO, 2018). Road crashes have (huge) impacts on people's lives, for example with respect to mental and physical health, ability to work and income, as well as on society including the health sector, labour market and government spending (ETSC, 2007; World Bank, 2017; World Bank, 2022). Road crashes affect welfare, which is reflected by several types of social costs that result from road crashes. Tangible costs include medical costs, loss of human productive capacities and damage to vehicle and other properties, while intangible impacts such as loss of quality of life are often also regarded as social costs (Alfaro et al., 1994; ETSC, 1997; World Bank, 2005; Bahamonde-Birke et al., 2015).

Understanding the impact of road crashes on welfare is important for evidence-based road safety policy making. This is reflected by the fact that the social costs of road crashes are regarded as a high-level outcome indicator for road safety management (Bliss & Breen, 2009). This is an indicator for the magnitude of road crashes as a social problem, which can be influenced by the implementation of road safety policies, among others. The social burden of road crashes is often stressed in road safety (policy) documents of international organizations, such as the World Health Organization (WHO, 2015), World Bank (2014) and the European Commission (EC, 2010), as well as in policy documents at the national level, for example in Australia (DoI, 2021), Canada (CCMTA, 2016), the Netherlands (IenW, 2018) and South Africa (DoT, 2016). In these documents, evidence on road crash costs is used to emphasize the need to improve road safety also from a socio-economic point of view. In some countries, comparisons are made with costs on other policy areas, for example congestion costs or costs of traffic emissions (Cambridge Systematics, 2011; SWOV, 2022), to point out their relative importance from a socio-economic perspective.

Improving road safety and reducing the negative impact of road crashes on welfare requires efficient spending of the available resources. Economic assessment methods can help decision makers prioritizing different investment options and allocating resources efficiently within the field of road safety or across several policy areas. In particular cost-benefit analysis (CBA) is widely used for assessment of transport projects (Mackie et al., 2014), including road safety interventions (ROSEBUD, 2005; EC, 2018). In CBA, all relevant societal impacts are quantified and expressed in monetary terms as much as possible, allowing a trade-off of the benefits and costs (Boardman et al., 2014). Conducting CBA of large transport projects is mandatory in several countries, for example Australia, New Zealand, the United States and several European countries (Mackie et al., 2014). Official guidelines for economic appraisal of transport projects recommend to include the road safety benefits of such projects and they provide monetary values of preventing road casualties (for example EC, 2014; USDoT, 2017).

Other economic assessment methods for injury prevention are cost-effectiveness analysis (CEA) and cost-utility analysis (CUA) (Polinder et al., 2012; Brent et al., 2014). CEA concentrates on the costs of interventions and their safety impacts and this method is aimed at calculating the costs per prevented casualty of different investment options. CUA is an advanced type of CEA which assesses the health benefits of investments using Quality Adjusted Life Years (QALYs). The outcome of CUA is the cost per QALY gained for alternative (road safety) investments. Particularly CUA is widely used in the field of public health and environmental issues, to assess the health gains of alternative treatments and to prioritize them (Brent et al., 2011; Drummond at al., 2015). Although CBA is the dominant approach in the literature on economic assessment of road safety measures (Polinder et al., 2012), CEA and CUA are also applied in the context of road safety (e.g. Tengs et al., 1995; Miller & Levy, 2000; Banstola & Mytton, 2016). These methods are particularly helpful for ranking different road safety measures and selecting the measures that maximize the safety or health impact given a certain budget, based on the costs per prevented casualty or costs per QALY gained. CBA has a broader scope because it takes all relevant societal impacts into account, relying on economic welfare theory. With respect to road safety investments, relevant welfare impacts not only include safety impacts, but also impacts on travel time, traffic emissions and health (other than safety impacts, e.g. health benefits of active travel modes such as cycling and walking). For that reason, and given its foundation in economic welfare theory, CBA is the only method that assesses the impact of road safety investments on welfare.

1.2. Current knowledge on social costs and cost-benefit analysis in the context of road safety and gaps in the literature

1.2.1. Social costs of road crashes

The social costs of road crashes have been estimated in many countries, particularly in high-income countries (WHO, 2015). Reviews of the social costs of road crashes in several countries, that were published in the period 1994-2000 (Alfaro et al., 1994; Jacobs et al., 2000; Elvik, 2000), found that the costs range from the equivalent of 0.5% to 5.7% of gross domestic product (GDP). They provide information on the contribution of cost elements to the costs, indicating that human costs have a major share (50% on average according to Elvik (2000)) in total costs. Recently, Bougna et al. (2022) published a review that concentrates on the size of the costs of road crashes (equal to 0.3% to 6.7% of GDP with a mean value of 1.9%) and on the influence of the main methodology. They find that the willingness to pay method results in higher costs than the human capital method (discussed below). In addition, the costs per fatality or per serious injury have been reviewed in a few studies (Elvik, 1995; Trawén et al, 2002; Hakkert & Wesemann, 2005). However, by focusing on the cost per casualty, these reviews do not provide insight into the national social costs of road crashes including the costs of minor injuries and property damage only crashes. It is striking that almost all reviews have been published about 20 years ago or earlier, which means that there is no recent detailed overview of the social costs of road crashes in individual countries and the methods used to estimate the costs.[1]

Different methodological approaches for estimating the social costs of road crashes have been discussed in the literature, specifically the restitution costs approach, human capital approach and willingness to pay approach (Alfaro et al., 1994; Dionne & Lanoie, 2004; Freeman et al., 2014; Bahamonde-Birke et al., 2015). These methods are aimed at estimating different cost elements of road crashes. The restitution costs approach is specifically aimed at estimating direct costs resulting from a road crash, such as the costs of hospital treatment and vehicle repair, while the human capital is aimed at estimating the loss of productive capacities of road casualties (Alfaro et al., 1994). The willingness to pay (WTP) approach was introduced around 1970 (Schelling, 1968; Mishan, 1971) to capture the intangible costs related to loss of quality of life and life years. Subsequent methodological discussions focused on the question whether or not a WTP method should be applied (Jones-Lee, 1982; 1990). Nowadays, there is consensus among most economists and road safety professionals that the WTP approach should be adopted, in addition to the restitution costs and human capital approaches, to capture the full costs of road crashes from a broad welfare economic perspective (Alfaro et al., 1994; Dionne & Lanoie, 2004; World Bank, 2005; Freeman et al., 2014; Bahamonde-Birke et al., 2015). Quite a few WTP studies in the context of road safety have been conducted since the mid-1970s. For example, De Blaeij et al. (2003) and Lindhjem et al. (2011) included respectively 30 and 37 WTP studies in the context of road safety in meta-analyses. Despite the availability of WTP values, reviews showed that the WTP approach was not generally adopted in estimates of the social costs of road crashes (Elvik 1995; Trawén et al., 2002), although a tendency towards using the WTP approach (in addition to other methods) was identified in high-income countries. Given the lack of more recent systematic reviews, there is no detailed international overview of the methods which are currently applied in studies on the social costs of road crash crashes and is unknown to what extent the WTP approach has been further integrated.

Particularly in low- and middle-income countries a combination of the three methodological approaches is not commonly applied in studies on the social costs of road crashes. Recently, studies were conducted in Egypt (Abdallah et al., 2016), Iran (Ainy, 2014; Ahadi & Razi-Ardakan,2015) and Sudan (Mofadal & Kanitpong, 2016), but in these studies either the human capital method or the willingness-to pay method has been applied. This implies that the full costs are underestimated, since each method captures different social cost elements. In addition, estimating the social costs of road crashes in low- and middle-income countries is known to be challenging due to lack of data (GRSF, 2020). This concerns data on the number of road crashes and casualties, which are known to be largely underreported particularly in low- and middle-income countries, as well as data on economic values related to the crashes and casualties.

Monetary values based on WTP are a key input for estimating the social costs of road crashes. Several reviews and meta-analyses of WTP-values in the context of road safety have been published (De Blaeij et al., 2003; Dionne & Lanoie, 2004; Lindhjem et al., 2011), but they focus on fatal risks only. The number of WTP studies aimed at non-fatal risks in the context of road safety is much more limited. This could be explained by the fact that determining the WTP for

[1] The review by Bougna et al. (2022) was published several years after this PhD research started. It concentrates on the influence of the general methodology and does not discuss the methods (e.g., cost items included and calculation methods) in detail.

non-fatal risk is more complex due to the large diversity of injury severities and the impacts of injuries on quality of life (Schoeters et al., 2020). A critical review of WTP studies on non-fatal risks in the context of road safety is missing in the literature, as well as an assessment of the methods which can be applied to determine the WTP for non-fatal risks. Consequently, the literature does not provide guidance on the most appropriate WTP method(s) for non-fatal road crash risk. This is striking, because injuries are likely to account for a large proportion of the social costs of road crashes given the high number of road injuries.

1.2.2. Cost-benefit analysis

CBA has been applied to a large variety of road safety measures in many studies. Daniels et al. (2019) conducted cost-benefit analyses of 29 road safety measures in different countries or regions, including infrastructure improvements, legislation, enforcement, education, post-crash treatment and vehicle equipment. They conclude that the benefits of most road safety measures (25 out of 29) outweigh their costs. This conclusion is consistent with previous CBA-studies in the field of road safety, which showed that many road safety measures are cost-beneficial (Winkelbauer & Stephan, 2005; CEDR, 2008). In a CBA of investments in the Sustainable Safety program implemented in the Netherlands in the period 1998-2007, a benefit-cost ratio of nearly 4:1 was calculated (Weijermars & Wegman, 2011). Elvik (2007) conducted a comprehensive CBA of four road safety programs in Norway, each consisting of a variety of road safety measures. This is one of the few examples of a CBA of road safety measures that took into account side effects on mobility, environment and health (other than road injury prevention). This CBA indicates that including side effects affects the size of the benefit to a limited extent: they account for 17% of the benefits at most.

Despite the fact that CBA is broadly applied in the field of road safety, this assessment method is not undebated. As discussed by Elvik (2001), the general applicability of the methodology of CBA to road safety has been criticized, and in particular the feasibility of determining a monetary value of saving lives (Hauer, 2011; Elvik, 2016). Also ethical issues related to applying CBA to road safety are subject to debate, including discussions on the distribution of safety impacts among individuals (Van Wee et al., 2014) and monetary valuation of preventing road casualties (Van Wee, 2011). A practical concern for road safety applications is the availability of data on costs and impacts of road safety measures (Daniels et al., 2019). Despite these concerns, applying CBA in the context of road safety has been advocated by academics (Evans, 2009; Asplund & Eliasson, 2016) as well as by governmental and non-governmental organizations who aim to improve road safety (ADB, 2003; AASHTO, 2010; PIARC, 2015). As noted by Van Wee (2012), it is important that researchers are aware of the methodological and ethical limitations of CBA and take these into account when conducting a CBA.

An issue which has not been addressed in the literature is the fact that the standard CBA-approach as applied in the CBAs and CBA guidelines discussed above, often fails to include the benefits of preventing non-fatal injuries accurately. The reason is that only a few severity categories are used to classify the crash outcome, typically fatal, injury (sometimes split into serious and slight) and property damage only crashes (AASHTO, 2010; PIARC, 2015; Daniels et al., 2019). However, several road safety measures are aimed at preventing specific types of crashes (for example run-off-road crashes or rear-end car crashes) which result in specific types of injuries (such as whiplash associated disorders in rear-end car crashes). The costs of medical treatment and the impacts of the injury on disability and quality of life, and thus the benefits of preventing injuries, depend on the type of injury (Polinder et al., 2005; 2007). Moreover, the standard CBA-approach is not able to assess the impacts on injury severity adequately, because the standard injury categories are too broad. For example, serious injuries are often defined as injuries requiring hospitalization with an overnight stay or for at least 24 hours (Schoeters et al., 2017). The severity of these injuries is very diverse and a reduction of injury severity within this category is not taken into account.

1.2.3. Summary of gaps in the literature

Based on the overview given above, the following gaps in the literature are identified:

1. There is no recent systematic overview of the social costs of road crashes as estimated in individual countries, the contribution of injury severity categories and cost elements to these costs, and the methodologies which have been used to estimate these costs.
2. The number of studies on social costs of road crashes in low- and middle-income countries is limited and they have methodological shortcomings, because they rely on one calculation method instead of a combination of methods which is needed to capture all relevant social costs.
3. The literature on willingness to pay for road crash risks is concentrated on fatal risks and does not critically discuss methods for determining the willingness to pay for non-fatal risks nor provide guidance on the most appropriate methods.
4. The calculation of the benefits of preventing non-fatal injuries in CBA does not consider injury type and injury severity at sufficient detail and a methodology for estimating these benefits at a more disaggregated level does not exist.

1.3. Aim, research questions and methods

This thesis is aimed at critically assessing the literature and current practices for estimating the impact of road crashes and road safety measures on welfare and at improving and applying methods for estimating these impacts.

Given this aim and the gaps in the literature as identified in Section 1.2, the following research questions will be addressed in this thesis:

1. Which methodologies are applied in individual countries to assess the welfare impact (or social-economic costs) of road crashes?
2. What is the size of this impact in individual countries and what is the breakdown of this impact into injury severity categories and cost elements?
3. What is/are the most appropriate method(s) to estimate the economic value of preventing non-fatal road injuries?
4. How can the estimation of the benefits of preventing non-fatal injuries in CBA be made more accurate and take into account impacts on specific types of injuries and injury severity?

Different methods will be used to address these research questions. Research questions 1 and 2 are aimed at reviewing and assessing current practices in analysis of the welfare impact of road crashes in individual countries as well as the results of these analyses. Two approaches will be applied to collect data on current practices and their results. Firstly, a literature review on the social costs of road crashes as estimated in individual countries worldwide will be conducted. Secondly, a survey among experts on road crash costs, including researchers, policy makers and other road safety professionals, will be conducted to collect data on the social costs of road crashes in European countries. The latter approach enables collecting data on official economic values of road crashes and injuries, as used by governmental organizations in economic assessment of road safety or broader transport projects, which may deviate from values found in the literature. Moreover, this approach enables to cover a larger number of countries because it does not require a publicly available publication. On the other hand, the level of detail is limited by the survey instrument (e.g. related to a maximum length of the questionnaire), while the literature review enables collecting data on road crash costs on a more detailed level. Research questions 1 and 2 will be answered mainly a by descriptive analyses of the data collected, including data on the methodologies used to estimate road crash costs, the size of the costs and breakdowns of the cost into injury or crash severity and cost elements.

In addition to providing overviews of the current practices in road crash costs analysis and their results, research question 2 will be addressed by a case study in Kazakhstan. This country is identified as one of the low- and middle-income countries lacking an estimate of the social costs of road crashes and having a relatively high road mortality rate (WHO, 2015). Information on road crash costs is expected to be helpful for policy makers in this country to raise more awareness of the road safety situation and its (economic) consequences and to spend the available resources efficiently. A hybrid methodological approach will be applied, which means a combination of valuation methods (restitution costs, human capital and willingness to pay approaches), in order to cover all relevant social cost elements (Alfaro et al., 1994). A household survey will be conducted to obtain detailed data on the costs at the individual level as well as on the willingness to pay for fatal risk reduction, in addition to data collection from national databases on economic, road safety and other statistics.

Research question 3 will be answered based on a critical assessment of methods for economic valuation of non-fatal risk reduction in the context of road safety. Valuation methods will be identified and classified, and their strengths and weaknesses will be assessed on the basis of a literature review. Following economic welfare theory, this review concentrates on willingness to pay methods. A set of criteria will be formulated to assess the appropriateness of each method for monetary valuation of non-fatal road injuries, using the results of the literature review. The main focus of this review is on *methods* for monetary valuation, whereas the literature review used to address research questions 1 and 2 is more focused on the *results* of studies. Furthermore, the literature review aimed at answering research question 3 concentrates on non-fatal injuries, whereas research questions 1 and 2 address all injury and crash severities (fatal, non-fatal and property damage only).

To answer research question 4, a CBA-methodology for road safety interventions will be developed using standard CBA-principles. Novel elements will be added for a more accurate estimation of the benefits of preventing non-fatal injuries, including a detailed classification of injury types and a linkage with human body model simulations. Human body models are able to simulate the impacts of a collision on the human body and to produce the changes in probabilities of specific injuries (Yang, 2018). The results of human body model simulations will be implemented in the CBA-methodology to estimate the benefits of preventing non-fatal injuries. To demonstrate the added value of the methodology, three cost-benefit case studies will be conducted. The methodology and case studies concentrate on vehicle safety, because several vehicle safety systems are particularly aimed at preventing specific types of crashes and injuries and/or at reducing injury severity.

1.4. Theoretical principles

1.4.1. Welfare

Assessing the impact of road crashes on welfare requires a good understanding and definition of 'welfare'. Welfare can be defined as the level of prosperity and standard of living of either an individual or a group of persons (Samuelson & Nordhaus, 2004). Different indicators for measuring welfare have been developed. Some indicators are directly linked to core economic processes, and they are aimed at measuring production, consumption and income. Common examples are the gross domestic product and gross national income. However, such indicators do not cover wider issues which influence the level of prosperity and standard of living and which are not reflected by market transactions and financial flows. Examples of such issues are health, safety and the availability of natural resources. Consequently, broader indicators for economic have been developed, particularly in the field of environmental economics. Examples include the 'Measure of economic welfare' (Nordhaus & Tobin, 1972) and the 'Index of Sustainable Economic Welfare' (Daly & Cobb, 1989), which include valuation of issues such leisure time, domestic work and environmental damage.

In this thesis a broad definition of welfare will be used, because the impact of road crashes goes beyond the impact on core economic processes such as generating income and production. Road crashes affect the well-being of the people involved in crashes, among others in terms of the impact on quality of life and longevity, which implies that a broad welfare perspective is needed. Welfare economic theory and the (related) theory of social cost-benefit analysis adopt a broad definition of welfare, which is not limited to material or financial issues (such as consumption, income and production) but also comprises intangible issues such as natural resources, quality of life and safety (discussed below). Welfare economic theory will be used to define the welfare impacts of road crashes.

1.4.2. Welfare economic theory

The tendency to include non-market issues in indicators for welfare is in line with economic welfare theory (see for example Johansson, 1991). According to this theory, each individual derives 'utility' from consumption as well as from intangible issues that affect quality of life. Other basic elements of welfare economic theory are the assumptions that individuals are the best judge of their own welfare ('consumers sovereignty') and that they aim to maximize their utility. The level of utility is affected by the choices people make with respect to using their income, time and human capacities. This in turn determines the level of welfare, since welfare is a function of the utility of all individuals in society. The most simple function specifies social welfare as the unweighted sum of the utility of all individuals in society. This is also referred to as the ‘potential Pareto criterion’, which means that a social welfare improvement occurs if there is a net utility gain, for example resulting from a government intervention, and if the people who receive a utility gain can potentially compensate the people who lose. Although more complex welfare functions have been developed in the literature (Varian, 1992), this welfare function is widely used, for example in CBA. It implies that distributional impacts are not taken into account (Sen, 2000). For example, if a project results in a welfare gain for rich people and a welfare loss for poorer people, this increased inequality is not considered in this welfare function. The same applies to distributional impacts of transport projects. For example: an infrastructure project may have positive welfare impacts (e.g., travel time gains) for many people, but negative welfare impacts for a small number of people (e.g., increased noise).

The concepts of willingness to pay (WTP) or willingness to accept (WTA) are used as measures of welfare changes or, in other words, to determine the economic value of goods and services (Freeman et al., 2014). This includes goods and services which are not traded on a market, such as safety, health and natural resources. The WTP is the amount of money an individual is prepared to pay for a utility gain, for example related to an increase in consumption of certain goods or services, while the WTA concerns the amount of money an individual wants to receive to compensate a utility loss. Several methods have been developed in the literature to determine the WTP or WTA for goods and services which are not traded on a market, including safety impacts. A distinction between stated preference and revealed preference methods is made (De Blaeij et al., 2003; Pearce et al., 2006). Stated preference methods use questionnaires asking people in a direct or indirect way their WTP (WTA) for positive (negative) impacts on their utility, such as improved air quality or safety. Revealed preference methods derive the WTP or WTA from people’s actual behaviour, such as their travel behaviour (using e.g., the costs of travelling to nature areas) or purchasing behaviour (using e.g., expenditures of safety devices). For a further discussion of these methods, see for example Freeman et al. (2014).

1.4.3. Cost-benefit analysis

Social cost-benefit analysis (CBA) has its foundation in welfare economic theory (Boadway & Bruce, 1984; Johansson, 1991; Boardman et al., 2011). This means that cost-benefit analysis is aimed at assessing the welfare impacts of (government) interventions in accordance with welfare economic theory. Hence, the monetary valuation of the impacts of the intervention, including road safety impacts in case of transport and road safety investments, should be consistent with economic welfare theory. For that reason, we adopt in this thesis the welfare economic theory as a basis to assess the impact of road crashes on welfare. This ensures that the results are suitable for application in cost-benefit analysis and thereby useful for road safety policy making and research. Since the impact of road crashes is negative, we utilize the terminology ‘social costs of road crashes’ to reflect the welfare impact of road crashes[2]. These costs include both material losses, such as damage to vehicles, and intangible losses related to loss of quality of life and life years. If an intervention has a positive impact on road safety, this impact is treated in cost-benefit analysis as a decrease of the social costs of road crashes.

[2] Alternatively, ´socio-economic costs’ is commonly used as a synonym (Alfaro et al., 1994; Trawén et al., 2002).

To account for distributional impacts (see above), distributionally weighted CBA has been proposed in the literature (Boardman et al., 2011). This means that different weights are assigned to the costs and benefits for different population groups. However, this approach has been criticized (Weisbach, 2015) and it is not commonly used in practice. For example, Dutch guidelines for CBA (Romijn & Renes, 2013) advise to present information on the distribution of benefits and costs among stakeholders in case there are important distributional impacts, but not to include them in the final outcome of the CBA (such as the balance of benefits and costs).

Although in CBA all relevant impacts are expressed in terms of money as much possible, (social) CBA should be distinguished from a financial analysis (Harlow & Windsor, 1988; Bonner, 2022). Financial transactions between parties do not (necessarily) represent a social cost or benefit. For example, a social security payment that the government pays as a compensation for income loss due to an injury, is not necessarily a social cost. It is only a money transfer (redistribution) from the government to the injured person. The true social cost of an injury is the loss of human productive capacity and loss of quality of life (further discussed below). However, an analysis of financial transactions can be useful to identify and quantify the distribution of benefits and costs (Bonner 2022).

1.4.4. The impact of road crashes on welfare

Following economic welfare theory, the social costs of road crashes consist of the loss of utility resulting from crashes, for example due to a reduction of a casualty's ability to consume or to enjoy life after a road crash. In addition, road crashes result in usage of resources needed to restore the utility level after a crash to the initial level as much as possible, which is regarded as a cost. For example, the value of resources (labour, equipment) needed to repair a damaged vehicle represents the cost of this vehicle damage. According to economic welfare theory, this value is determined by the 'opportunity costs' of the resources. The opportunity costs of using a resource are defined as 'its value in its best alternative use' (Buchanan, 1991; Boardman et al., 2016): the value that society must forgo if the input is used to produce a certain good or service. The idea is that resources that are used for, for example repairing a car, cannot be used for producing something else (that would bring forth utility) and this is regarded as a cost. In cost-benefit analysis, usually market prices are used as a proxy for the value of resources in its best alternative use under the assumption that markets function well (Boardman et al., 2011). The prices of resources (in this case the price of labour and equipment that is needed to repair a car) are used then to estimate the costs (e.g., the costs of vehicle damage).

The three methods for estimating the social costs of road crashes which are recommended in the literature (as discussed in Section 1.2) are rooted in the concepts of welfare economic theory. The restitution (or 'reproduction') costs method is aimed at valuing the resources needed to restore road casualties and their relatives and friends to the situation which would exist if they would not have involved in a road crash (Alfaro et al., 1994; Bahamonde-Birke et al., 2015). The concept of opportunity costs is applied to estimate these costs. This method is applicable to the costs of medical treatment of road injuries, vehicle damage, costs of emergency services and insurance costs, which are valued based on the opportunity costs of the resources needed to restore this damage as much possible. The human capital approach is aimed at valuing the loss of human capacities (Mushkin & Collings, 1959; Freeman et al., 2014). Following economic welfare theory, the loss of human capital should be valued on the basis of opportunity costs. In this case the opportunity costs consist of the value of the production that a road casualty would have produced if he or she was not injured or killed in a road crash. The WTP approach is aimed at the utility loss resulting from road crashes (Mishan, 1971). In this approach, people's WTP for a reduction in the risk of being killed or injured in a road crash is determined, using stated or revealed preference methods.

1.5. Summary and organization of this thesis

Table 1.1 summarizes the gaps in the literature, research questions and methods that will be applied to answer these questions, as discussed in this chapter. The research questions are addressed in five chapters, as indicated in the table.

Table 1.1: Research questions, methods, related gaps in the literature and thesis chapters addressing each research question.

Research question	**Method**	**Literature gap**	**Thesis chapter**
1. Which methodologies are applied in individual countries to assess the welfare impact (or social-economic costs) of road crashes?	(a) Literature review of road crash costs estimates worldwide (b) Analysis of official road crash costs estimates in European countries, based on a survey	There is no recent and systematic overview of the social costs of road crashes in individual countries and methodologies used	2 (a) 3 (b)
2. What is the size of this impact in individual countries and what is the breakdown of this impact into injury severity categories and cost elements?			
	Case study on road crash costs in Kazakhstan	Number of studies on social costs of road crashes in LMIC is very limited ad they have methodological shortcomings	4
3. What is/are the most appropriate method(s) to estimate the economic value of preventing road injuries?	Literature review and critical assessment of appropriateness of WTP methods for reducing non-fatal risks	There is no critical and systematic discussion of WTP methods for reducing non-fatal road crash risk and no guidance on most appropriate method	5
4. How can the estimation of the benefits of preventing non-fatal injuries in CBA be made more accurate and take into account impacts on specific types of injuries and injury severity?	Development of a CBA-methodology with novel elements, including a detailed classification of injury types and linkage to human body models; application in three case studies	The calculation of the benefits of preventing non-fatal injuries in CBA does not take into account injury type or injury severity at sufficient detail, and a methodology does not exist.	6

The thesis is organized as follows:

Chapter 2 presents the literature review on the social costs of road crashes as estimated in individual countries worldwide. This review provides a detailed overview of road crash cost studies, discusses the methodologies used in these studies and summarizes the results of the studies in terms of the size of the costs and breakdowns of the cost into injury or crash severity and cost elements.

In Chapter 3, an analysis is made of the official road crash cost estimates in European countries, as used by governmental organizations in economic assessment of road safety or broader transport projects, based on the survey among experts from each country.

Chapter 4 presents the case study on the social costs of road crashes in Kazakhstan. The total costs and costs per casualty, by severity level and cost component, are estimated applying a hybrid methodological approach. The chapter includes an estimation of the human costs of road injuries based on a willingness to pay survey.

In Chapter 5, WTP-methods for monetary valuation of preventing non-fatal road injuries are reviewed and critically assessed. Based on a literature review, a classification of methods is presented, and an overview of the values found in the literature (by type of method) will be given and discussed. Recommendations on the most appropriate method(s) for future research are given.

Chapter 6 presents the novel methodology for including the benefits of preventing non-fatal injuries in CBA, using a detailed classification of injuries and a linkage with human body model simulations to estimate injury (severity) reductions. Three cases studies on vehicle safety systems are included to illustrate the added value of the methodology.

In Chapter 7, the research questions addressed in this thesis are answered based on the findings in chapters 2-6. Conclusions and recommendations are made for policy making and research in the field of road safety and some strengths and limitations of this research are discussed.

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2. Social costs of road crashes: an international analysis

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Abstract

This paper provides an international overview of the most recent estimates of the social costs of road crashes: total costs, value per casualty and breakdown in cost components. The analysis is based on publications about the national costs of road crashes of 17 countries, of which ten high income countries (HICs) and seven low- and middle-income countries (LMICs). Costs are expressed as a proportion of the gross domestic product (GDP). Differences between countries are described and explained. These are partly a consequence of differences in the road safety level, but there are also methodological explanations. Countries may or may not correct for underreporting of road crashes, they may or may not use the internationally recommended willingness to pay (WTP)-method for estimating human costs, and there are methodological differences regarding the calculation of some other cost components.

The analysis shows that the social costs of road crashes in HICs range from 0.5% to 6.0% of the GDP with an average of 2.7%. Excluding countries that do not use a WTP- method for estimating human costs and countries that do not correct for underreporting, results in average costs of 3.3% of GDP. For LMICs that do correct for underreporting the share in GDP ranges from 1.1% to 2.9%. However, none of the LMICs included has performed a WTP study of the human costs.

A major part of the costs is related to injuries: an average share of 50% for both HICs and LMICs. The average share of fatalities in the costs is about 23% and 30% respectively. Prevention of injuries is thus important to bring down the socio-economic burden of road crashes.

The paper shows that there are methodological differences between countries regarding cost components that are taken into account and regarding the methods used to estimate specific cost components. In order to be able to make sound comparisons of the costs of road crashes across countries, (further) harmonization of cost studies is recommended. This can be achieved by updating and improving international guidelines and applying them in future cost studies. The information regarding some cost components, particularly human costs and property damage, is poor and more research into these cost components is recommended.

Keywords: road crashes, costs, fatality, injury, value of a statistical life, transport economics

2.1. Introduction

Information about the social costs of road crashes is important for evidence-based policy making. It provides insight into the consequences of road crashes for the economy and social welfare. The high socio-economic burden of road crashes is often stressed in (policy) documents of international organizations such as the World Health Organization (WHO, 2015), World Bank (2013) and European Commission (EC, 2010), as well as in documents on the national level, to emphasize the need to improve road safety also from an economic point of view. Information about the costs is also useful for comparing costs of road crashes with costs in other policy areas, as an input for priority setting across policy areas. Furthermore, information about costs of road crashes is needed in cost-benefit analyses (CBA) that are used to estimate the social return of investments in road infrastructure and road safety, and to help prioritizing (road safety) measures. In CBA the costs per casualty or crash are used to estimate the benefits of road safety improvements and compare these with the costs of the safety measure and with other benefits of e.g. infrastructure improvements.

International comparison of the costs of road crashes is useful to gain insight in differences in the economic burden of road crashes across countries, and is used as an input for estimating global road crash costs. Based on international comparisons, the social costs of road crashes have previously been estimated at about 1% of Gross Domestic Product (GDP) in low-income countries to about 2%-3% in high income countries (Jacobs et al., 2000; Elvik, 2000). However, these estimates are based on costs studies in the 90s or earlier, and probably underestimate the costs of road crashes (WHO, 2004). Some other international comparisons (e.g. Elvik 1995; Trawén et al, 2002; Hakkert & Wesemann, 2005) are aimed at comparing the costs per fatality or per serious injury, which is useful for CBAs but which does not provide insight into the national social costs of road crashes including costs of minor injuries and property damage only crashes (Tay, 2002). Further, comparing the methods used to estimate these costs is very useful, since previous studies (Elvik, 1995; Trawén et al, 2002) show that methodological differences are an important explanation for differences in cost estimates.

The aim of this paper is to provide an international overview of the costs of road crashes and to describe (differences in) the methodologies. The most recent cost estimates in 17 countries are analysed. In section 2.2 the method used for this international comparison and the selection of countries is described. Section 2.3 provides an overview of the costs components that are taken into account in cost studies in these countries, and discusses the methods used to estimate these costs. In section 2.4 the results of costs studies of 17 countries are compared, in particular the total costs of road crashes and the share in GDP, values per casualty, distribution of the total costs among crash severity and the breakdown in cost components. Section 2.5 contains a discussion of the main results and section 2.6 gives conclusions and recommendations.

2.2. Method and selection of countries

The international comparison of the costs of road crashes in this paper is based on the most recent publications about these costs in specific countries. Only countries for which a sufficiently detailed report or paper is available about the costs and the methods used to estimate these costs, written in English, German or Dutch, are included. This resulted in a selection of 17 countries, of which eight Asian countries, six European countries, Australia, New Zealand and the US. The costs of road crashes in the Asian countries, most of which are low- or middle-income countries, have been studied in the context of a larger study by the Asian Development Bank (ADB, 2005a). For each Asian country the costs of road crashes have been studied and published separately, enabling us to include these countries in this overview. Among the selected countries are ten high income countries, five middle income countries and two low-income countries. Table 2.1 shows the countries that are included, the income level (GDP per capita) in these countries, motorization rate, the year for which the costs of road crashes have been estimated, and the reference(s) for each country.

Previous studies (Jacobs, 2000) found that the costs of road crashes as a share of GDP depend on national income per capita. Therefore, in this analysis the costs of road crashes in high income countries (HICs) will be compared to those in low- and middle-income countries (LMICs). Table 2.1 shows to which income category each country belongs, as classified by the World Bank on the basis of gross national income per capita.

Table 2.1: Overview of the countries included in this review: GDP per capita, motorization rate, year for which costs of road crashes have been estimated and references used.

Country	**Country characteristics**		**Cost studies**	
	GDP/capita (2013, US$ PPP)*	**Motorvehicles per 1000 people (2010)****	**Year**	**Sources**
HICs				
Australia	43,544	698	2006	BITRE (2009)
Austria	45,493	578	2011	Sedlacek et al. (2012)
Belgium	41,663	559	2002	De Brabander & Vereeck (2005), De Brabander (2005)
Germany	44,469	572	2005	Baum et al. (2007)
Netherlands	46,298	527	2009	De Wit & Methorst (2012), Wijnen (2012)
New Zealand	34,826	712	2012	Ministry of Transport (2006; 2013)
Singapore	78,763	149	2001	ADB (2005g)
Switzerland	56,565	566	2003	Sommer et al. (2007), Ecoplan (2002)
UK	38,452	518	2012	DfT (2013), McMahon (1994), Hopkin & O'Reilly (1993)
US	53,042	782	2010	Blincoe et al. (2014), Trottenberg & Rivkin (2013)
LMICs				
Cambodia	3,041	21	2002	ADB (2005b)
Indonesia	9,561	66	2002	ADB (2005c)
Lao PDR	4,822	22	2003	ADB (2005d)
Myanmar		7	2003	ADB (2005e)
Philippines	6,536	30	2002	ADB (2005f)
Thailand	14,394	160	2002	ADB (2005h)
Vietnam	5,294	14	2003	ADB (2005i)

* Source: World Bank (2015); not available for Myanmar.

** Source: World Bank (2015); Cambodia 2005 data, Lao PDR and Vietnam 2007 data.

2.3. Costing methods

2.3.1. Cost Components

In international guidelines (Alfaro et al., 1994; BRS&TRL, 2003) five components of the costs of road crashes are distinguished:

- medical costs: costs resulting from the treatment of casualties, e.g. costs of hospital stay, rehabilitation, medicines and adaptations and appliances for the handicapped;
- production loss: loss of production and income resulting from the temporary or permanent disability of the injured, and the complete loss of production of fatalities; gross production loss includes consumption loss (see Section 3.2).
- human costs: immaterial costs through suffering, pain, sorrow and loss of life or of quality of life;
- property damage: damage to vehicles, freights, roads and fixed roadside objects;
- administrative costs: in this category the costs of police services, fire brigade services, law courts and administrative costs of insurers are taken into account.

Table 2.2 gives an overview of the cost items that each country includes. All countries in this overview follow the international guidelines by distinguishing between the five main cost components, which have a share of at least 94% in total costs (see Section 4.3). The LMICs do not take into account other cost components, while most HICs additionally include costs of congestion resulting from road crashes. Costs of congestion may include environmental costs, in addition to costs of time losses. Some HICs also include costs of unavailability of damaged vehicles.

Between countries, there are differences in the cost items that are taken into account within the five main cost categories. In addition to lost market production, four countries take into account unpaid production loss (e.g. household work). Loss of unpaid production can have a significant share in total production loss: in the US for example about 25% of all production loss concerns unpaid work. Four countries also separately estimate *friction costs*: the costs of recruitment and training of new employees. In Switzerland and the US these cost are about 5% of production loss, and in Australia and Germany less than 1%.

Almost all countries include human costs of fatalities, serious and minor injuries. Exceptions are the Netherlands and the Philippines that do not include of minor injuries. Nine countries, among which three LMICs, take into account other property damage besides vehicle damage, mainly damage to infrastructure. It is estimated at 1% of total property damage in Australia, about 10% in Austria, Germany and Myanmar, and up to 20% in Lao PDR (for other countries this proportion is not documented). Concerning administrative costs almost all countries include police costs and insurance costs. Legal costs and costs of fire department are not always taken into account.

Besides these costs, *avoidance costs* may be a relevant cost component (Van Wee, Hagenzieker & Wijnen, 2014). These are the costs that occur when people adapt their travel behaviour because of perceived safety levels, such as changing travel mode, route, destinations or the decision whether or not to travel at all. Examples are: older persons that may prefer to stay at home (e.g. during snowy weather) because they think travelling is too risky, or parents that choose to bring their children to school by car instead of by bicycle. Studies into these avoidance costs related to congestion have been done in the Netherlands, and these costs appear to have a significant share (30% to 40%) in total congestion costs (KiM, 2012). To the authors' knowledge, no such studies have been carried out in the field of road safety however.

In the remainder of this section we discuss the methods used to estimate the main costs components: production loss, human costs and property damage.

Table 2.2: Cost items included in national road crash costs studies.

	Medical costs				Production loss			Human costs			Property damage		Administrative costs				Other		
Country	Emergency transport	Hospital	Follow -on treatment	Medicines, appliances	Paid	Unpaid	Friction	Fatalities	Serious injuries	Minor injuries	Vehicles	Other	Police	Legal	Fire department	Insurance	Congestion	Vehicle unavailability	Funerals
HICs																			
Australia	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Austria	x	x	x		x			x	x	x	x	x	x	x	x	x	x	x	
Belgium	x	x	x	x	x			x	x	x	x	x	x	x	x	x	x		x
Germany	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x
Netherlands	x	x	x	x	x			x	x		x		x	x	x	x	x		x
New Zealand	x	x	x		x			x	x	x	x		x	x					
Singapore	x	x	x		x			x	x	x	x		x			x			
Switzerland		x	x	x	x		x	x	x	x	x		x	x		x			x
UK	x	x	x	x	x	x		x	x	x	x	x	x			x		x	x
US	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
LMICs																			
Cambodia	x	x	x		x			x	x	x	x		na	na	na	na			x
Indonesia	x	x	x	x	x			x	x	x	x		x			x			x
Lao PDR	x	x		x	x			x	x	x	x	x	x			x			x
Myanmar	x	x	x	x	x			x	x	x	x	x	x			x			x
Philippines	x	x	x	x	x			x	x		x		na	na	na	na			
Thailand	x	x	x		x			x	x	x	x		x		na	x			x
Vietnam	x	x	x	x	x			x	x	x	x		na	na	na	na			

na: no information available

2.3.2. Production loss

To estimate production loss the human capital method is used in all countries in this overview. In this approach the (loss of) productive capacity of a human being is valued, based on figures of productivity or income per capita, and estimates of the period of time casualties are unable to work (Freeman, 2003). In the literature the human capital approach has been considered as an approach to value human life, as an alternative for the WTP approach. However, the human capital approach is used to estimate (loss of) production, while the WTP approach is used to estimate (loss of) quality of life. Therefore, the human capital approach and the WTP approach should be considered as complementary (Wijnen et al., 2009). Both approaches include a component of consumption loss however, which means that a correction is needed to avoid double counting. In most countries consumption loss is deducted from the VOSL, resulting in human losses. Consumption loss is then included in production loss (known as gross production loss). Exceptions are Belgium and Switzerland that include consumption loss in the human costs. These two countries calculate the net production loss (gross production loss minus consumption loss). To calculate unpaid production loss surveys of time spending are used, in combination with indicators for the costs of time (like wage or costs of hiring personnel).

2.3.3. Human costs

According to international guidelines (e.g. Alfaro et al., 1994) and state of the art economic theory (e.g. Boardman et al., 2006), human costs should be estimated by using a willingness to pay (WTP) method. This means that the amount of money that people are prepared to pay for a reduction in crash risk is estimated by using a stated preference (SP) method or revealed preference (RP) method (De Blaeij et al., 2003). RP methods value risk reductions on the basis of actual behaviour, for example purchasing behaviour regarding safety provisions, while SP methods use questionnaires in which people, directly or indirectly, are asked how much they are willing to pay for safety provisions. From the WTP for risk reductions the 'value of a statistical life' (VOSL) is derived. The VOSL comprises the valuation of human costs as well as a value of consumption loss (section 3.2). Thus, subtracting consumption loss from the VOSL results in the value of human costs (Evans, 2001; Wijnen et al., 2009).

Table 2.3 gives an overview of the VOSL or human costs per fatality (depending on which values are documented) for each country, the year for which the VOSL has been estimated, and the method. In seven HICs included in this overview human costs are based on WTP. Four of them use a country-specific VOSL, and the other three countries use a standard European VOSL that has been determined in studies such as HEATCO (Bickel et al., 2006) and UNITE (Nellthorp et al., 2001). Australia and Germany estimate the human costs on the basis of compensation payments as determined in law courts or statutory values. Singapore and all LMICs use a rule of thumb as proposed in a guideline for cost studies in developing countries (BRS &TRL, 2003), meaning that human costs are estimated as fixed proportions of the total costs per fatality, serious injury and minor injury respectively (BRS&TRL, 2003). These proportions are arbitrary values derived in the 1980s, and they are originally based on the difference between production and consumption in the UK. This difference was added to net production loss in order to prevent a negative result for elderly (who do not contribute to production) (TRL, 1995). Table 2.3 shows that the values per fatality based on WTP are orders of magnitude higher than those based on compensation payments. Also the rule of thumb that

Asian countries use leads to relatively low values, in absolute terms as well as a proportion of the total costs of a fatality: in HICs that use a WTP value human costs have a share of 54% to 85% in the costs of a fatality, whereas this is 14% to 28% in LMIC.

The VOSL in countries that use the WTP method are within 2 - 3 million US$, except the US (9.2 million US$). The high value in the US may be explained by methodological differences within the WTP approach: the US value is based on RP studies into the valuation of occupational risks, while the VOSL in other countries is based on SP studies on road safety risks. Moreover, some countries have chosen a relatively conservative VOSL (e.g. Netherlands and EU-values; Wijnen et al., 2009), to avoid overestimating road safety benefits when the VOSL is applied in cost-benefit analysis. Differences in base year may explain some further differences in VOSL.

Table 2.3: Value of a statistical life (VOSL), human costs per fatality, year for which VOSL has been estimated, and methods used.

Country	**VOSL (human costs + consumption loss) (million US$ 2012)***	**Human costs per fatality (million US$ 2012)***	**Base year VOSL**	**Method**
HICs				
Australia	-	0.4	n.a.	Compensation payments
Austria	2.8	2.0	1998	WTP, EU-value
Belgium	2.9	-	1998	WTP, EU-value
Germany	-	0.04	n.a.	Compensation payments
Netherlands	3.0	2.4	2001	WTP, country-specific
New Zealand	2.5	-	1991	WTP, country-specific
Singapore		0.5	n.a.	% cost fatality, rule of thumb
Switzerland	2.4	-	1998	WTP, EU-value
UK	-	1.7	1991	WTP, country-specific
US	9.2	8.0	1997-2003	WTP, average of nine country-specific studies
LMICs				
Cambodia	-	0.008	n.a.	% cost fatality, rule of thumb
Indonesia	-	0.05	n.a.	% cost fatality, rule of thumb
Lao PDR	-	0.002	n.a.	% cost fatality, rule of thumb
Myanmar	-	0.01	n.a.	% cost fatality, rule of thumb
Philippines	-	0.03	n.a.	% cost fatality, rule of thumb
Thailand	-	0.06	n.a.	% cost fatality, rule of thumb
Vietnam	-	0.02	n.a.	% cost fatality, rule of thumb

* The values in local currencies are converted into US$ price level 2010 using GDP deflators and Purchasing Power Parities (World Bank, 2015; except Myanmar: IMF, 2014).

Regarding human losses related to injuries, country-specific values are only available in the UK and the US. In the UK a WTP study has been carried out for serious and minor injuries. In the US the values of injuries are based on 'quality adjusted life years' (QALYs). For five injury categories, based on the Maximum Abbreviated Injury Scale (MAIS, Gennarelli & Wodzin, 2005), the number of QALYs has been estimated and the human costs are calculated using a value per QALY. Australia and Germany use compensation payments as an indicator for the human costs of injuries, and in the Asian countries the rule of thumb mentioned above is applied. The other countries use the ratio between the human costs of a (serious or minor) injury and the VOSL that is found in other countries or recommended in European studies. These ratios are based on studies into the human costs of road injuries in the UK (Hopkin & O'Reilly, 1993; O'Reilly et al., 1994) and Sweden (Persson, 2004).

2.3.4. Property damage

The majority of property damage concerns damage to vehicles. In most countries the estimation of the size of this damage is based on insurance data. One of the major problems regarding this cost component is the fact that not all damage is claimed, because of no-claim premiums for example, and that not all damage is covered by insurances. However, all countries in this overview have included an estimate of damage that is not claimed or not covered by insurances. In most countries this is done by deriving the average vehicle damage per crash (in most cases for different crash severities) from insurance data, and estimating the number of crashes on the basis of police reports or insurance data. A drawback of this approach is that the estimate of the number of crashes, particularly crashes with property damage only, is uncertain due to underreporting. In other countries the vehicle damage estimates are based on the payments by insurance companies, and a separate estimate of the non-claimed damage using insurance data and crash registrations. These estimates of non-claimed damage range from 18% (Austria) to about 50% (Netherlands) of total vehicle damage. The UK is the only country where a study into the non-claimed damage has been carried out using questionnaires (Taylor, 1990). This study showed that in about half of the cases a claim is submitted to an insurance company, and that in those cases the average damage per case is about three times higher than in cases without a claim. This suggests that the total amount of damage that is not claimed amounts to about 25% of all vehicle damage.

Regarding damage to infrastructure in most cases the estimates are based on damage registrations by road authorities.

2.4. Comparison of the costs of road crashes

2.4.1. Total costs and costs per casualty

Figure 2.1 shows the costs of road crashes as a percentage of GDP in high income and low/middle income countries.[3] In HICs the share of the costs of road crashes in GDP ranges from 0.5% to 6.0%, with an (unweighted) average of 2.7%. The estimates of Singapore (0.5% of GDP) do not include a correction for underreporting of road crashes however, hence these cost estimates are a significant underestimation. If we exclude Singapore, the two HICs that do not use a WTP method to estimate the human costs, Australia and Germany, have the lowest share in GDP of the remaining countries. As human costs have a great share in the total costs (see Section 4.3), the method used to estimate these costs has a considerable influence on the

[3] See the appendix for more details on the costs in each country.

total costs. If those countries that do not correct for underreporting and those that do not use a WTP method (as recommended by international guidelines) are excluded, the average share of the cost of road crashes ranges from 1.7% to 6.0 % of GDP with an average of 3.3%. The average shares of the costs of road crashes in GDP in LMICs, that all do correct for underreporting, range from 1.1% to 2.9% with an average of 2.2%. Hence, the share of the costs in GDP is considerably lower than in HICs, especially in HICs that use a WTP method.

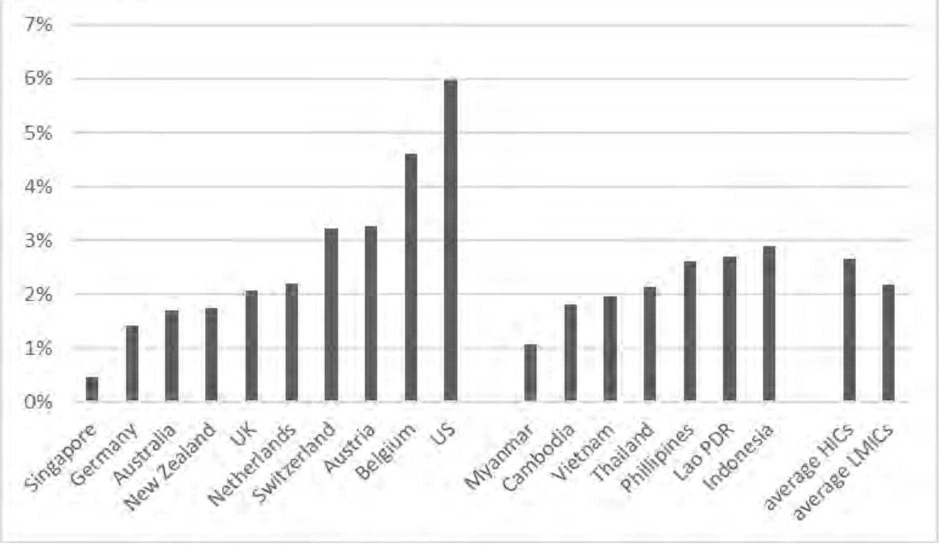

Figure 2.1: Costs of road crashes as a percentage of GDP.

Differences between countries regarding the share of the costs in GDP can be explained by differences in the number of crashes and casualties as well as by differences in the costs per crash or casualty and methods used to estimate these costs. Table 2.4 shows the costs per casualty (fatalities, serious injuries and minor injuries) or crash (property damage only, PDO). The costs per casualty include crash costs such as property damage and administrative costs.[4] It shows that the costs per fatality in HICs are much higher than in LMICs. This is mainly explained by differences in the valuation of human costs, since human costs have a major share in the costs per fatality. However, also within the HIC group there are major differences due to differences in methodology. In Australia, Germany and Singapore the costs per fatality are relatively low, which is explained by the fact that these countries do not apply a WTP method.

The costs per serious and minor injury are more difficult to compare because of differences in the definitions of a serious and minor injury. However, Table 2.4 shows that the costs per serious and minor injury in LMICs are much lower than in HICs. Within the HIC group the costs per

[4] In some countries the costs per casualty include injury related costs only (medical costs, production loss and human costs). In those cases we have calculated the crash related costs per casualty on the basis of costs per crash (property damage and administrative costs) and the number of casualties (per injury category) per crash, and added them to the costs per casualty.

serious and minor injury in Australia, Germany and Singapore are again relatively low because of the method used to estimate human costs of injuries. The costs per minor injury in the Netherlands are relatively low because human costs are not taken into account for these injuries.

Table 2.4: Costs per casualty (fatalities, serious injuries and minor injuries) and per crash (property damage only), US$, price level 2012.

Country	**Costs per casualty, 1000 US$, price level 2012**			**Costs per crash**
	Fatality	Serious injury	minor injury	Property damage only
HICs				
Australia	2,197.4	219.0	12.1	8.2
Austria	3,649.2	461.5	32.5	6.3
Belgium	n.a.	n.a.	n.a.	n.a.
Germany	1,391.7	144.2	5.9	3.9
Netherlands	3,181.5	341.8	7.7[3]	4.3
New Zealand	2,384.4	252.1	13.4	1.8
Singapore	1,840.8	165.6	15.9	4.4
Switzerland	2,893.8	523.6[1]	25.6[1]	n.a.
UK	2,514.5	282.6	21.8	3.0
US	9,502.7	753.6[2]	21.0[2]	4.0
LMICs				
Cambodia	31.8	12.5	1.0	0.8
Indonesia	229.8	15.0	4.3	0.5
Lao PDR	13.0	3.8	0.7	0.5
Myanmar	60.1	19.8	4.4	7.7
Philippines	176.0	19.6	5.4	4.7
Thailand	319.5	15.9	2.4	2.2
Vietnam	119.7	30.9[4]	-	0.8

[1] Switzerland distinguishes four injury categories and three age groups; the costs per serious injury are an average of the three most serious injury categories, weighted by number of casualties and age.
[2] The US calculates the costs per MAIS-category (Maximum Abbreviated Injury Scale); the costs per serious and slight injury are an average of MAIS 2-5 and MAIS 0-1 respectively.
[3] The Netherlands distinguishes two minor injury categories (emergency room treatment and no hospital treatment, including treatment by a general practitioner only); the costs of minor injury are a weighted average of these two categories.
[4] Vietnam does not distinguish between serious and minor injuries; this figure refers to all injuries.

Higher costs per casualty explain a higher share in GDP in HICs. However, also the number of casualties determines the share of the costs in GDP. This explains why the share of the costs in GDP in some HICs (such as the Netherlands, New Zealand and the UK) is lower, or not much higher, than in some LMICs. A better road safety performance in HICs leads to relatively low costs (as a proportion of GDP), despite higher costs per casualty.

Figure 2.2 shows the relation between the costs per fatality and GDP per capita, showing that costs per fatality increases more that proportionally with increasing GDP per capita. This is related to the estimation method for human costs (that have a large share in costs per fatality): LMICs do not use the WTP method resulting in lower values for human costs. Differences in labour productivity between lower and higher income countries as well as differences in life expectancy (resulting in lower human costs and production loss in LMICs) may also explain this relationship. The actual reasons behind the relation between costs per fatality and GDP per capita were not researched.

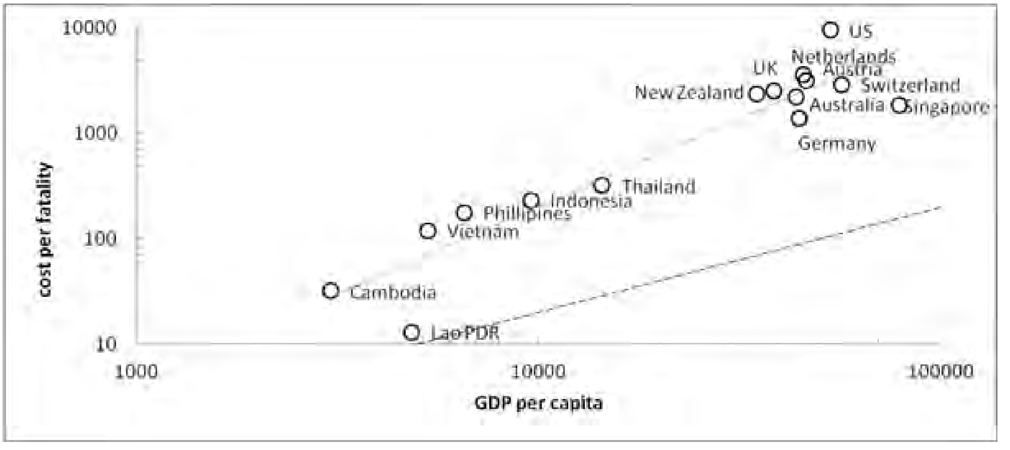

Figure 2.2: Relation between cost per fatality and GDP per capita for the countries selected in this paper. The solid line is a guide to the eye only. It represents cost per fatality proportional to (GDP per capita)$^{1.66}$. The dashed line represents an arbitrary linear relation.

2.4.2. Costs per severity category

Figure 2.3 shows the distribution of the total costs among fatalities, serious injuries, minor injuries and property damage only crashes.[5] In Singapore the costs of reported casualties only are calculated, leading to an upward bias in the share of more severe casualties. For that reason Singapore is excluded from Figure 2.3. For Belgium and Vietnam this distribution is not known.

The figure shows that both in HICs and LMICs half of the costs is related to injuries, of which about two thirds are serious injuries. Fatalities account for 23% (HICs) to 30% (LMICs) of the costs, and about a quarter to a fifth of the costs results from property damage only crashes. The main difference between HICs and LMICs is that the share of fatalities in the total costs is higher in LMICs. This may be related to the relatively high number of fatalities in LMICs as compared to the number of injuries.

[5] The share of PDO crashes for Austria includes property damage resulting from injury crashes, resulting in a overestimation of the share of PDO crashes. Since injury crashes have a share of only 5% in the total number of crashes in Austria, this overestimation is probably slight (even though the damage per injury crash is higher than per PDO crash).

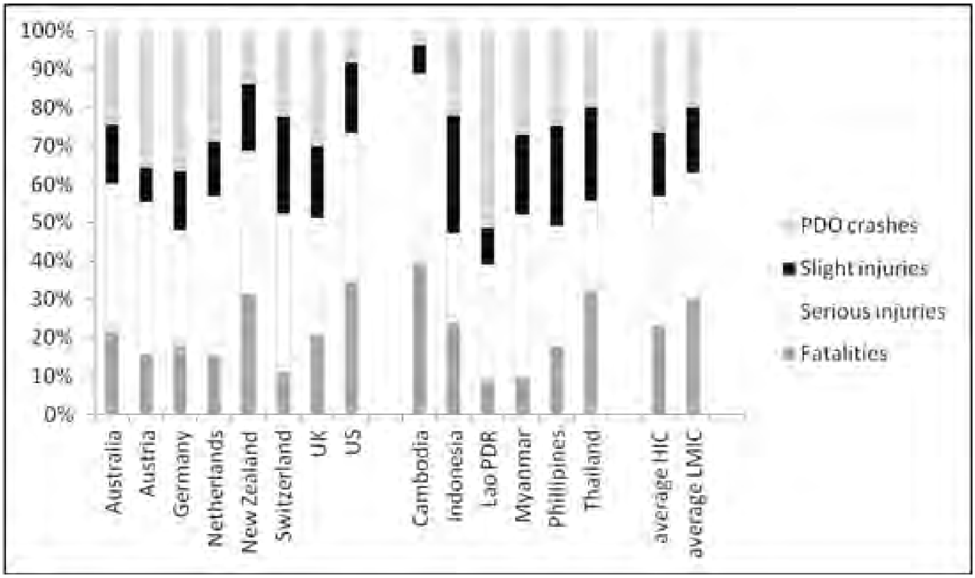

Figure 2.3: Distribution of total costs among fatalities, serious injuries, minor injuries and property damage only (PDO) crashes.

2.4.3. Distribution among cost components

Figure 2.4 shows the shares of the cost components in the total costs of road crashes for each country and the averages for HICs and LMICs.[6] In the HICs human costs have a major share in the total costs: the (unweighted) average share is 40%. In countries that do not apply a WTP method (Australia, Germany and Singapore) this share is much lower, because WTP methods result in much higher human costs per casualty (see Table 2.3). If these three countries are excluded, the average share of human costs for the remaining countries amounts to 54% of the total costs. In LMICs the share of human costs is much lower (average 18%) which is explained by the lower value of human costs per casualty.

In LMICs property damage has the largest share in the total costs (on average 39%). Mark that the number of PDO crashes is uncertain because of (very) incomplete crash reporting. In most countries (particularly LMICs) assumptions such as a fixed ratio of PDO crashes and injury crashes have been used to estimate the number of PDO crashes. Two explanations for this relatively high share of PDO crashes are observed however. Firstly, human losses are valued relatively low in LMICs, which obviously leads to larger shares of the remaining components. Secondly, in LMICs the costs per PDO crash are relatively high as compared to costs that are injury related: the ratio of the costs of a PDO crash and the costs of a minor injury is twice as high in LMICs as compared to HICs, and the ratio of the costs of a PDO crash and the costs of a serious injury is eight times higher in LIMCs as compared to HIC (see also Table 2.4). This indicates that injury related costs, particularly human costs, have a relatively low value as

[6] Excluding New Zealand because human costs and production loss with respect to fatalities are not calculated separately in New Zealand.

compared to the value of vehicle damage. This may be explained by differences in income level that result in relatively lower values of a statistical life in LMICs, as well as by differences in the methodologies used to estimate human costs (see section 2.3.3).[7]

Beside human costs and property damage, production loss is an important cost component, having an average share in total costs of 20% in HICs and 23% in LMICs. Medical costs are relatively low, particularly in HICs, as well as administrative costs.

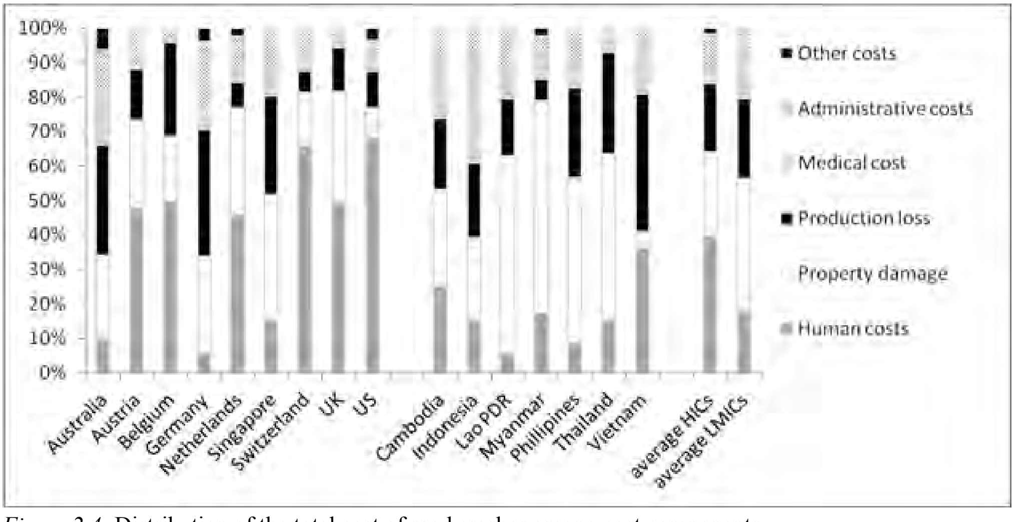

Figure 2.4: Distribution of the total cost of road crashes among cost components.

2.5. Discussion

Regarding the methodology used to estimate road crash costs several differences between countries have been observed in our analysis.

Firstly, this relates to the cost components that are included in the cost estimates. Although all countries in this overview take into account the cost components that have been recommended in international guidelines, some high-income countries incorporate additional cost components (congestion, costs of vehicle unavailability) and also within the main cost components there are differences regarding unpaid production loss, friction costs, damage to infrastructure and human costs of minor injuries. Particularly in LMICs unpaid production may have a significant impact on the estimates of production loss where a larger share of (e.g. agricultural) production is used for personal consumption.

Secondly, differences between countries are observed regarding the methods used to estimate separate cost components. This particularly concerns human costs: the internationally recommended WTP approach results in (much) higher values than other approaches that are

[7] Note that the share of PDO crashes in the total costs (Figure 2.3) is much lower than the share of total property damage. This is because fatal and injury crashes also result in property damage. Property damage has in particular a major share in the costs of minor injury crashes.

used in several countries. The application of WTP has a significant impact on total costs because of the large share of human costs in total costs. Moreover, the quality of human costs estimates is questionable: there are just a few countries that use a country-specific estimate of the value of a statistical life, and these values tend to be outdated. In addition, there are very few studies into the human costs of injuries. WTP-based estimates of human costs are particularly lacking in LMICs. This may be related to methodological difficulties (are poor people able to answer questions about small risks and their willingness to pay to reduce these risks?) and practical reasons (expensive studies). Using values from other countries may be a solution, and thus the question how to 'transfer' values between (high and low) income countries is a relevant topic for future research.

Regarding property damage, another major cost component, difficulties arise in most countries regarding the availability and quality of data. Insurance data does not cover all property damage, because not all damage results in submitting an insurance claim. Moreover, it is difficult to deduct the average damage per crash from insurance data, since numerous smaller damage amounts are more likely not to be claimed. Also underreporting of property damage only crashes is high, which makes it difficult to estimate these costs. Due to these difficulties the estimates of property damage are uncertain, as recognized in most cost studies. An appropriate alternative to obtain information about these costs, as has been done once in the UK (Taylor, 1990), would be to use questionnaires among road users about their involvement in crashes, the damage resulting from these crashes, and payments by insurance companies.

The differences in cost components that have been included and in methods that have been used to estimate each cost component, imply that the cost estimates cannot easily be compared across countries. Moreover, cost estimates in some countries are not consistent with international guidelines. Costs are particularly underestimated in countries that do not use the recommended WTP method. In addition, differences in cost estimates may also result from more detailed methodological issues that are not covered by international guidelines.

In the literature standardized valuations, related to GDP or GDP per capita, have been used or proposed to estimate the costs of road crashes. Firstly, in calculations of the global costs of road crashes (Jacobs et al., 2000; WHO, 2004) the costs of road crashes were estimated at 1% (LMICs) to 2% (HICs). These proportions are rough estimates, and the figures for the countries discussed in this paper show that these proportions probably (hugely) underestimate the costs of road crashes. However, as the number of countries in this overview is limited, a study on a larger scale is recommended to obtain figures that are more representative on the global level. Secondly, value transfer functions relating the VOSL to GDP per capita have been developed (Milligan et al., 2014; McMahon & Dahdah, 2008; Miller, 2000). These functions may be used as a rule of thumb to estimate the costs per fatality and total costs of fatalities if a country-specific VOSL is not available. However, this approach is based on the VOSL and thus only includes human costs and consumption loss. Moreover, as shown in this paper, the share of fatalities in total costs is limited and therefore estimating the costs of (all) injuries as well as property damage only crashes is needed to gain insight into the full social costs of road crashes. Furthermore, it is questionable whether road crash costs can be estimated on the basis of GDP (per capita) alone. Road safety performance, and hence the costs of road crashes, depend on many factors like motorization rate, road safety investments, speed limits and culture, and these factors may only to a limited extent be related to GDP.

2.6. Conclusions and recommendations

In this overview the total costs of road crashes are found to be 2.7% of GDP in the HICs and 2.2% of GDP in the LMICs (unweighted averages). In (high income) countries that use a willingness to pay method to estimate human costs, as recommended in international guidelines, total road crash costs have a share of 3.3% in GDP. This is much higher than the proportions that have been used in previous studies to estimate global road crash costs.

Half of the costs of road crashes is related to injuries, in both HICs and in LMICs. The share of fatalities in the costs is 'only' 23% in HICs whereas in LMICs 30% of the costs is related to fatalities. This may indicate that the efforts in HICs to prevent fatalities have been effective, resulting in a lower economic burden of fatalities. The challenge for most HICs now is to bring down the (economic) burden of road injuries, particularly serious injuries, as well.

Several methodological differences between countries have been observed. This concerns firstly the cost components that are taken into account. Although a cost classification as recommended by international guidelines is applied by all countries, there are differences regarding loss of unpaid production, property damage other than vehicle damage (particularly damage to infrastructure), human costs of minor injuries, congestion costs and costs of vehicle unavailability. Secondly, there are differences regarding the methods used to estimate specific cost components. This concerns particularly human costs: several countries, mainly LMICs, do not use the internationally recommended willingness to pay method, resulting is a substantial underestimation of the costs of road crashes.

In order to be able to make sound international comparisons we recommend (further) harmonization of cost studies regarding cost components to be included as well as methods to be used to estimate each cost component. Updating and improving international guidelines and applying them in future cost studies is needed to achieve this harmonization, which will improve the reliability of cost estimates in individual countries. This will provide policymakers with accurate and internationally comparable information on the economic burden of road crashes, that can be used for emphasizing the (economic) need to improve road safety and to set policy priorities. Moreover, more accurate information on costs of road crashes is particularly needed for cost-benefit analysis of road safety investments or (other) transport investments.

A cost component that is missing in cost studies as well as in international guidelines are avoidance costs: cost of adapting travel behaviour because of (perceived) low safety levels. No studies have been done yet regarding these safety costs, but there are examples of studies into the avoidance costs related to congestion. It is recommended to study the (potential) avoidance costs and develop methods to estimate these costs.

Finally, the information regarding some cost components is poor and more research into these cost components is recommended. This particularly regards human costs of fatalities in low- and middle-income countries, human costs of injuries (in all countries), and property damage.

Appendix

Table A1 shows the costs of road crashes for each country. The costs (expressed in the local currency) and the share in GDP are taken from the reports per country (see Table 2.1). In case the share in GDP is not stated in the country report, the share in GDP has been calculated using GDP figures published by the World Bank (2015). The costs are converted into US$ price level 2012, using GDP deflators (World Bank, 2015) and Purchasing Power Parities (World Bank, 2015; except Myanmar: IMF, 2014).

Table A1: Total costs of road crashes and share in GDP

Country	**Costs, million, local currency**	**Currency, year**	**Costs, million US$ 2012**	**Share in GDP**
HICs				
Australia	17,849	AU$, 2006	14,709	1.7%
Austria	10,088	€, 2011	12,205	3.3%
Belgium	12,524	€, 2002	17,377	4.6%
Germany	31,477	€, 2005	43,029	1.4%
Netherlands	12,496	€, 2009	15,224	2.2%
New Zealand	3,840	NZ$, 2013	2,479	1.7%
Singapore	699	S$, 2001	914	0.5%
Switzerland	14,078	CHF, 2003	10,734	3.2%
UK	34,300	£, 2012	50,620	2.1%
US	870,826	US$, 2010	904,790	6.0%
Average HICs				2.9%
LMICs				
Cambodia	66,064	US$, 2002	103,690	1.8%
Indonesia	41,396,056	Rupiah, 2002	29,061	2.9%
Lao PDR	47	US$, 2003	85,387	2.7%
Myanmar	94,814	MK, 2003	1,008	1.1%
Philippines	105,260	P, 2002	8,967	2.6%
Thailand	115,932	B, 2002	12,983	2.1%
Vietnam	11,034,000	D, 2003	4,209	2.0%
Average LMICs				2.2%

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3. An analysis of official road crash cost estimates in European countries

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Abstract

This paper gives an overview of official monetary valuations of the prevention of road crashes, road fatalities and injuries in 31 European countries. The values have been made comparable by converting them to Euro in 2015-values, adjusted by purchasing power parities. The monetary valuation of preventing a fatality varies from 0.7 to 3.0 million Euro. The valuation of preventing a serious injury ranges from 2.5% to 34.0% of the value per fatality and the valuation of preventing a slight injury from 0.03% to 4.2% of the value of a fatality. Total costs of road crashes are equivalent to 0.4% to 4.1% of GDP. The method used for obtaining valuations has a major impact on values. Most countries rely on the willingness-to-pay (WTP) approach, which gives higher valuations than other methods. Additional explanations for variations in valuations are differences in the cost components included, different definitions of serious and slight injuries and different levels of underreporting. Harmonization of valuation practices is needed for making sound international comparisons of road crash costs and for cost-benefit analysis at supranational level.

Keywords: costs; road crash; fatality; injury; economic valuation; willingness to pay

3.1. Introduction

Information about road crash costs is needed for at least two purposes. Firstly, road crash costs are regarded as a high-level outcome indicator for road safety management (Bliss & Breen, 2009). This indicator reflects the magnitude of road crashes as a socio-economic problem, which is influenced by the implementation of road safety policies, among others. Secondly, road crash cost information is used in economic assessments of road safety programs or broader transport projects. In cost-benefit analysis, road crash cost savings reflect the monetary valuation of the benefits of road safety improvements. Consequently, official guidelines for economic appraisal of transport projects usually include monetary valuations of preventing road casualties (for example EC, 2014; USDoT, 2017).

Several international reviews of road crash costs have been made in the past (Wijnen & Stipdonk, 2016; Trawén et al., 2002; Elvik, 2000; Elvik, 1995; Alfaro et al., 1994). However, a comprehensive review covering all current European Union countries has not been conducted yet. Alfaro et al. (1994) concentrated on 14 European countries, while the other studies included countries from several continents (including Europe). This paper aims to fill this gap by presenting a review of road crash costs in 31 European countries, including an assessment of the size of road crash costs (total and costs per casualty and crash), the methods used to estimate these costs, and explanations for differences in cost estimates between countries. The study was conducted within the European Horizon2020 project SafetyCube, which is aimed at developing a road safety Decision Support System (DSS) for road safety policy makers and other stakeholders. This system includes a tool for conducting cost-benefit analyses of road safety measures, using country-specific information on road crash costs. The information on crash costs was collected in collaboration with the European Horizon2020 project InDeV (Kasnatscheew et al, 2016). This paper concentrates on the official values as applied by governmental organizations in economic assessment of road safety or broader transport projects. Note that in some countries other cost estimates are available, for example from academic studies, and that these values may deviate from the values officially used by the government. In Belgium for example, academic studies on road crash costs have been conducted (De Brabander & Vereeck, 2007; De Brabander, 2006), but the results of these studies are not adopted in the governmental guidelines for economic appraisal (RebelGroup, 2013). Policy makers may tend to choose relatively conservative values. For example, the European Conference of Ministers of Transport deliberately choose a value of a fatality that was lower than the scientifically most accurate estimate (ECMT, 1998). Other examples include Belgium, where a higher value of a fatality found by De Brabander (2006) was not used as a standard governmental value, and the Netherlands, where a value of a fatality at the lower bound of a range was chosen as the official value (Wesemann et al., 2005). Given these discrepancies, the present study focuses on the crash costs that are applied by the government and does not include crash costs from other sources.

3.2. Method for the analysis of official national cost values

To enable a comparative analysis of monetary valuations of road safety in European countries, a framework was defined, consisting of a classification of the main cost components, underlying cost items within each component and methods to estimate each cost item. The framework was based on guidelines for estimating road crash costs, in particular the European COST313 guidelines (Alfaro et al., 1994) and best practices as identified in international reviews of road crash cost studies (Wijnen & Stipdonk, 2016).

The main cost components included in the framework are:

1. Medical costs, such as costs of hospitalization, rehabilitation and other medical treatment;
2. Production loss: the loss of production or productive capacity of road casualties;
3. Human costs: immaterial cost of pain, grief, loss of quality of life and lost life years;
4. Property damage, such as damage to vehicles and infrastructure.
5. Administrative costs: costs related to police for attending road crashes, fire service, insurance and legal costs;
6. Other costs, such as funeral costs, congestion costs and vehicle unavailability.

In addition, three valuation methods are identified for estimating these cost components:

1. The restitution costs approach, which comprises estimates of the costs of resources that are needed to restore road casualties and their relatives and friends as much as possible to the situation which would exist if they had not been involved in a road crash. These costs can be interpreted as the direct costs resulting from a crash, such as the costs of hospital treatment and vehicle repair. This approach is typically used to estimate medical costs, property damage and administrative costs, as these costs are associated with restoring the consequences of road crashes. Usually market prices are used to value these costs, if available. For example, costs of vehicle damage are calculated using the price of repairing a vehicle, which represents the value of the resources (e.g. labour and materials) used to repair the vehicle.
2. Human capital (HC) approach: in this approach the value for society of the loss of productive capacities of road casualties is measured. This approach is suitable for estimating production loss. The HC approach can be used to estimate either the actual production loss or the potential production loss. The first concerns the market production of casualties who are employed, while the latter refers to what casualties could potentially produce. Potential production loss takes into account the loss of productive capacities of unemployed people as well as future production of children. Future production is discounted using a social discount rate.
3. Willingness to pay (WTP) approach: in this approach costs are estimated on the basis of the amount individuals are willing to pay for a risk reduction. This approach is generally recommended as the most appropriate method to estimate human costs (Freeman et al., 2014; Boardman et al., 2011; Alfaro, 1994), since there is no market price for these costs. Stated preference or revealed preference methods are used to determine the WTP (see e.g. Bahamonde-Birke et al., 2015; De Blaeij, 2003). Revealed preference methods value risk reductions on the basis of actual behaviour, for example purchasing behaviour regarding safety provisions such as airbags. Stated preference methods use questionnaires in which people, directly or indirectly, are asked how much they are willing to pay for reducing their crash risk. Although both types of methods are valid, reviews show that stated preference methods are much more commonly used in the field of road safety, particularly in Europe (Lindhjem et al., 2010; De Blaeij et al., 2003).

> Despite several types of potential bias related to using surveys (Bahamonde-Birke et al., 2015; Boardman et al., 2011), stated preference methods are often preferred because of their broader applicability and independence of information on actual (purchasing) behaviour. Moreover, consumers are usually not (fully) aware of the risk reduction resulting from safety devices and stated preference methods allow providing this information to respondents to help them understand (small) risk reductions correctly (Lindhjem et al., 2010).

Note that willingness to pay estimates comprise, in addition to a valuation of immaterial loss of quality of life, a valuation of consumption loss, which overlaps with production loss. Consequently, a correction for consumption loss should be made to avoid double counting (Wijnen et al., 2009). In this respect a distinction is commonly made between gross production loss (including consumption loss) and net production loss (excluding production loss). It is common practice to use the concept of gross production and to deduct consumption loss from WTP estimates (Wijnen & Stipdonk, 2016).

The framework is discussed in more detail in Wijnen et al. (2017). Based on this framework a questionnaire was developed, including questions on:

- Costs per casualty and per crash, per cost component and by severity level. Seven cost categories were distinguished based on the severity level: fatalities and fatal crashes, serious injuries and serious injury crashes, slight injuries and slight injury crashes, and property damage only (PDO) crashes.
- Cost items included in each cost component.
- Methods and databases used to estimate each cost item.
- Total costs of all casualties and crashes and their percentage of Gross Domestic Product (GDP).
- Year of the cost estimates (primary study and updates).
- Number of crashes and casualties by severity level and definitions of severity levels.

Official cost figures as used by governmental organizations were requested. Experts from 32 European countries (28 EU-countries, Iceland, Norway, Serbia, and Switzerland) were contacted by sending them a standardized email and asked for literature and other information on road crash costs in their country. The questionnaire was filled in by the researchers as completely as possible on the basis of this literature and then sent to the country experts for checking and completion. Validation checks were performed with a few key indicators to check consistency of values and avoid errors, e.g. a check whether costs per casualty were equal to total costs of casualties divided by number of casualties (for each severity level). The experts were contacted again for validating cases where errors were suspected or for providing additional information. Official cost figures were obtained from 30 countries. The information provided by the Lithuanian expert was not used, because it did not reflect the official figures. A governmental report was used instead (LRA, 2015). Portugal was added using figures from Donário & Dos Santos (2012). The information provided by the Portuguese expert was not used because it was internally inconsistent. No data were obtained for Romania.

An integrated dataset was created by reading in the MS Excel questionnaires using MS Visual Basic. This dataset was exported to a delimited text file and written to a SQLite database (Hipp et al., 2016), using R (R Core team, 2018). The further data cleaning and data analysis took place in this database. Several quality checks were carried out, in particular concerning data completeness and internal consistency. Modifications of the data were done where appropriate, such as adding missing data that could be calculated from data in other parts of the questionnaire or data from other sources. For example, if the total cost as a percentage of GDP was missing, this figure was calculated using total costs from the questionnaire and GDP from Eurostat. In addition, the data were specified according to the severity categories for crashes and injuries in the questionnaire. Finally, all costs figures were converted into Euro and price level 2015 using GDP deflators and Purchasing Power Parities (PPP) from Eurostat. A detailed description of the data processing is given by Wijnen et al. (2017).

3.3.Results

3.3.1. Costs per fatality

The survey shows that the official estimates of costs per fatality range from €0.7 million to €3.0 million (Figure 3.1).

There are three potential explanations for the differences in costs per fatality:

- Differences in the definition of a road fatality.
- Differences in costs components that have been included.
- Differences in methods used to estimate each cost component.

Regarding the definition of a road fatality, 95% of the countries (N=21) apply the criterion that a casualty who dies within 30 days after the crash (and as a result of the crash) is regarded as a road fatality.[8] Consequently, differences in definitions are not a main explanation for differences in the costs per fatality.

Concerning cost components, Figure 3.2 (a 'heatmap') shows how many countries have included each cost component in the costs per casualty and costs per crash by severity level. The black colour indicates that most countries have included a cost component while light grey indicates that few countries have included a cost component. This shows that the majority of countries have included the injury- related costs components (medical costs, production loss and human costs) in costs per fatality (as well as in costs per serious and slight injury). However, crash-related costs (property damage, administrative costs and most of the other costs) are not always included. This is partly explained by the fact that several countries have strictly separated casualty-related and crash-related costs. They include casualty-related costs only in costs per casualty and crash-related costs only in costs per crash, while other countries have assigned crash-related costs to casualties using information on number of casualties per crash.

[8] For 10 countries the definition of a road fatality was not filled in in the questionnaire. Most probably most of these countries have used the same definition, as the 30 day criterion is the international standard (Eurostat et al., 2009).

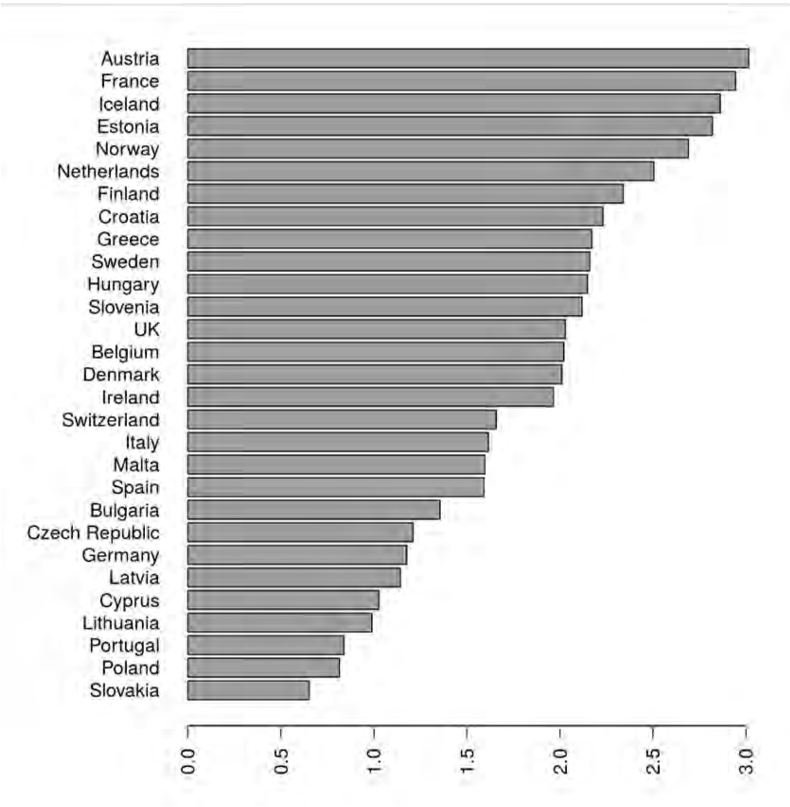

Figure 3.1: Costs per fatality (Million EUR 2015, adjusted for PPP; N=29; no data available for Luxembourg and Serbia).

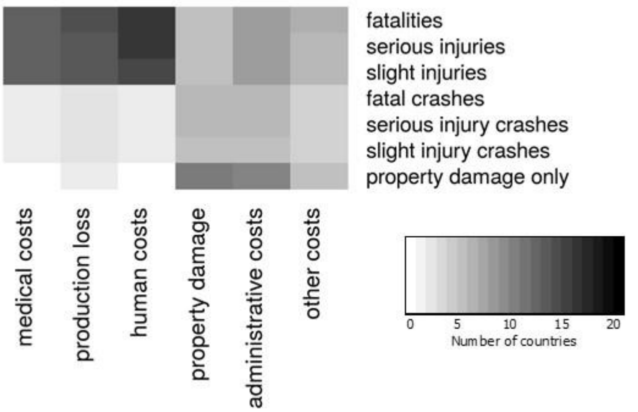

Figure 3.2: Heatmap of the number of countries which have included each cost component in costs per casualty and crash by severity level.

The results of our survey show that differences in valuation methods across European countries mainly concern human costs. For other cost components, in general there is consensus on the method to be used: human capital approach for production loss and the restitution costs approach for most other cost components. Figure 3.3 shows the method that is used to estimate human costs of fatalities in each country.[9] Most countries (n=18) apply a WTP method, while three countries use the human capital method (which in fact does not measure human costs but production loss). Two countries apply the restitution costs method. In this case the restitution costs method means that the valuation of a fatality is based on payments made to relatives to compensate their immaterial losses. For the remaining countries the method is not known (other method or no information available).

Human costs based on a WTP method are found to be much higher than values based on the compensation payments or the human capital approach. Consequently, total costs per fatality are much higher in WTP countries than in other countries since human costs represent a major share in the total costs per fatality in countries that apply the WTP approach (54% to 94%), see Figure 3.4.

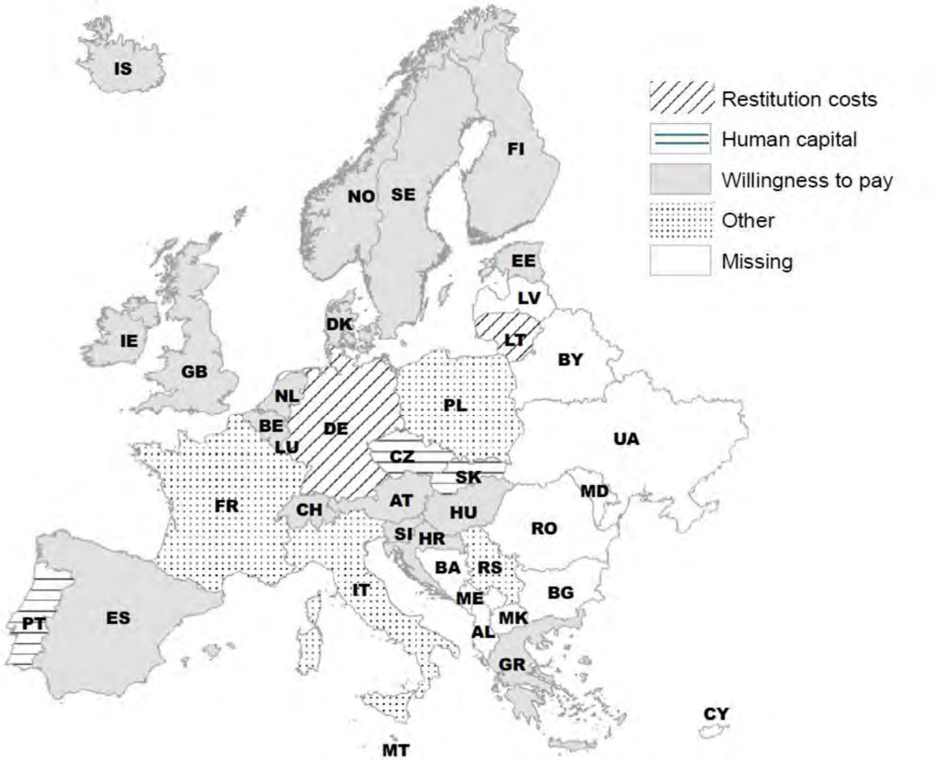

Figure 3.3: Methods used to estimate human costs of fatalities.

[9] In the questionnaire information on the method per cost component was asked for, but not separately for fatalities and serious and slight injuries. We assume that the information on the methods applies (at least) to fatalities.

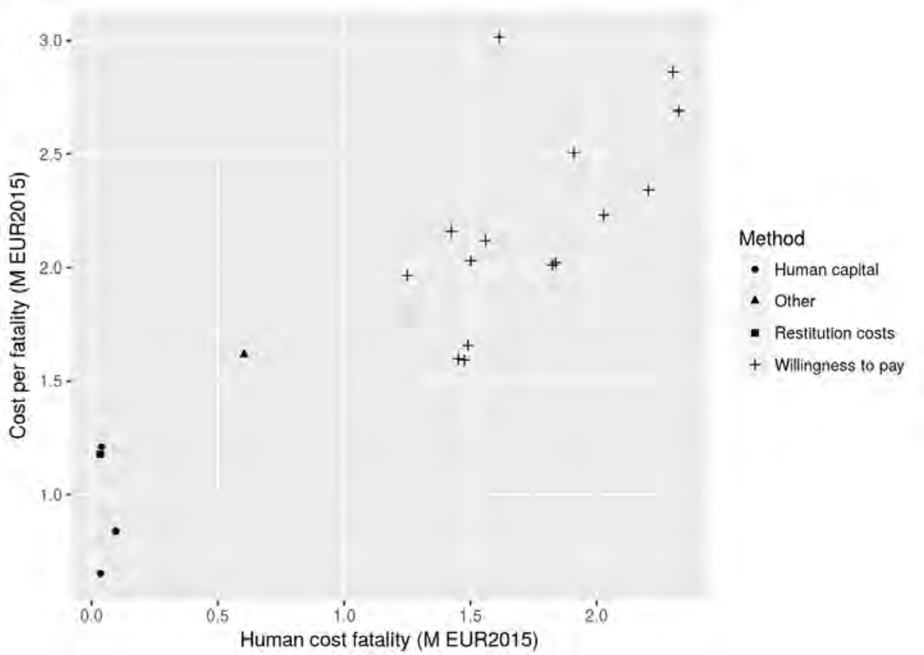

Figure 3.4: Relation between human costs per fatality, total costs per fatality and method for estimating human costs.

3.3.2. Costs per serious and slight injury

The costs of a serious injury range from 2.5% to 34.0% of the costs of a fatality (Figure 3.5).[10] Although this is a very wide range, about three quarters of the countries have a value between 10% and 20% of the value of a fatality. This is probably explained by the fact that information on the human costs of serious injuries is very limited, while these costs have large share in total cost per serious injury (51% to 91% in countries using a WTP method). Schoeters et al. (2017) note that only a few European countries conducted WTP study on non-fatal risks: Belgium (De Brabander, 2006), Sweden (Persson et al., 1995; Persson, 2004) and the UK (O'Reilly et al., 1994). Most other countries use the results from the studies in these countries, or they apply a standard percentage of the value per fatality as proposed in European projects (for example the HEATCO project; Bickel et al., 2006). Of course, the variation in the actual values per serious injury is still large (€28,000-€959,000) because there is variation in the human costs per fatality, from which the costs per serious injury are derived. Costs of a slight injury show even more variation: these costs range from 0.03% to 4.2% of the costs of a fatality (Figure 3.6). The range of actual values is extremely wide: €296 to €71,742.

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[10] Poland is excluded, because the costs per serious injury was stated to be higher than the costs per fatality. This seems to be implausible, because human costs are included in both costs per fatality and cost per serious injury.

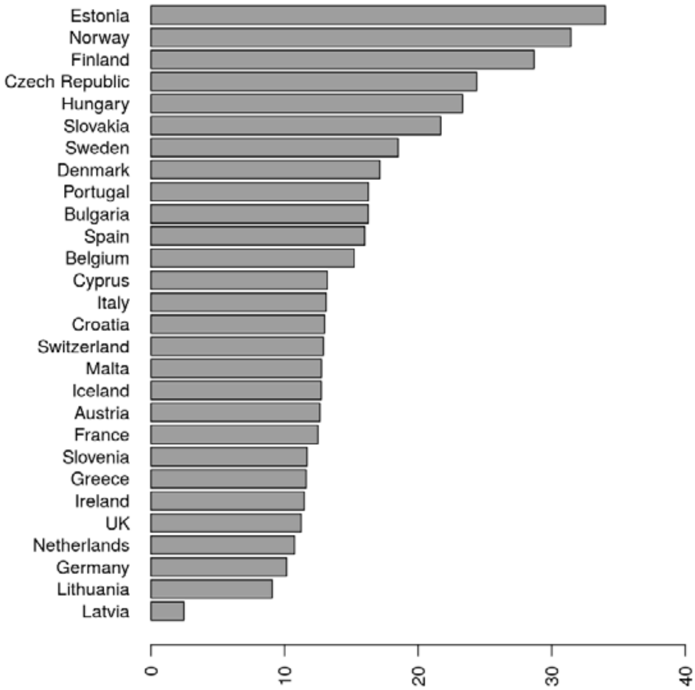

Figure 3.5: Costs per serious injury as a percentage of the costs per fatality. (N=28; no data available for Luxembourg and Serbia and Poland is excluded).

Three explanations for the variations in costs per serious and slight injury can be put forward. Firstly, the individual countries use different definitions of injuries. Some countries use a criterion based on hospital admission (at least 24 or 48 hours for serious injuries), while other countries use a definition based on the type and severity of the injuries. Also a minimum duration of inability to work and payment of disability benefits are used as criteria in some countries. Secondly, the reporting rate (by the police or hospitals) of injuries may affect the average costs of injuries. A higher reporting rate usually implies that more injuries of lower severity are included in the casualty statistics, resulting in a relatively lower average value per injury. A lower number of serious injuries relative to the number of fatalities is accompanied by relatively higher costs of a serious injury (Figure 3.7).[11] Thirdly, differences in cost components included and methodological differences may explain the differences in costs per serious and

[11] Greece and Latvia are regarded as outliers and therefore are excluded in this graph. In Greece the ratio of number of fatalities/number of serious injuries is extremely high compared to other countries and in Latvia the ratio of costs per fatality/costs per serious injury is extremely high. Without these two countries the relation between the two ratios is significant at the 1% level. If these countries are included the relation is non-significant however.

per slight injury. Just as for fatalities, several countries do not include crash-related costs, while casualty-related costs are included by most countries (Figure 3.2). Regarding methods, the main difference concerns the estimation of human costs (WTP or other methods), similar to fatalities.

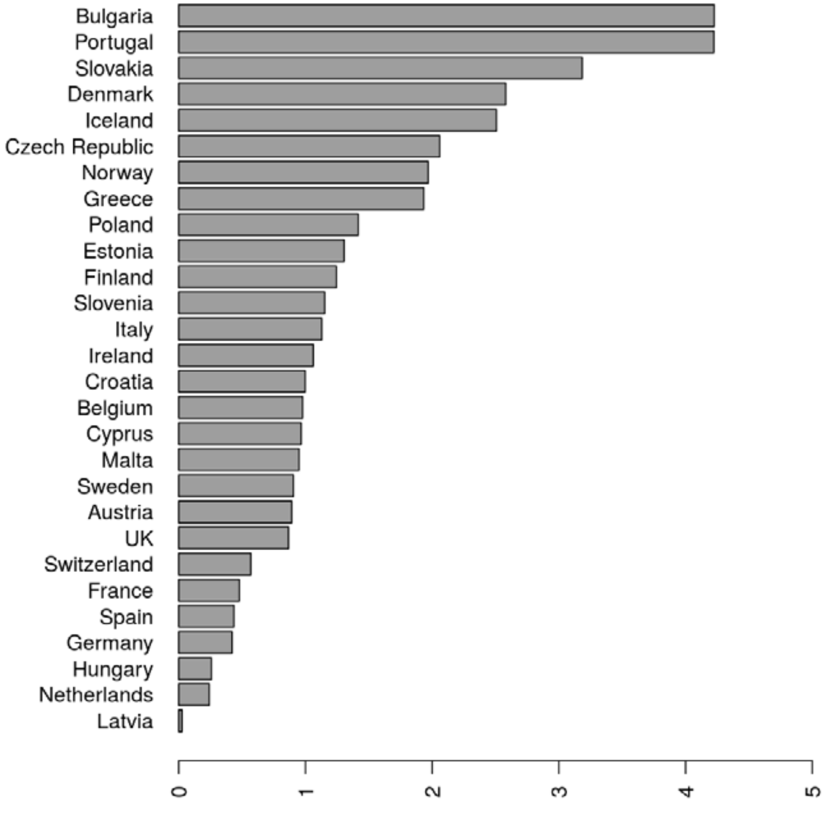

Figure 3.6: Costs per slight injury as a percentage of the costs per fatality (N=28; no data available for Lithuania, Luxembourg and Serbia).

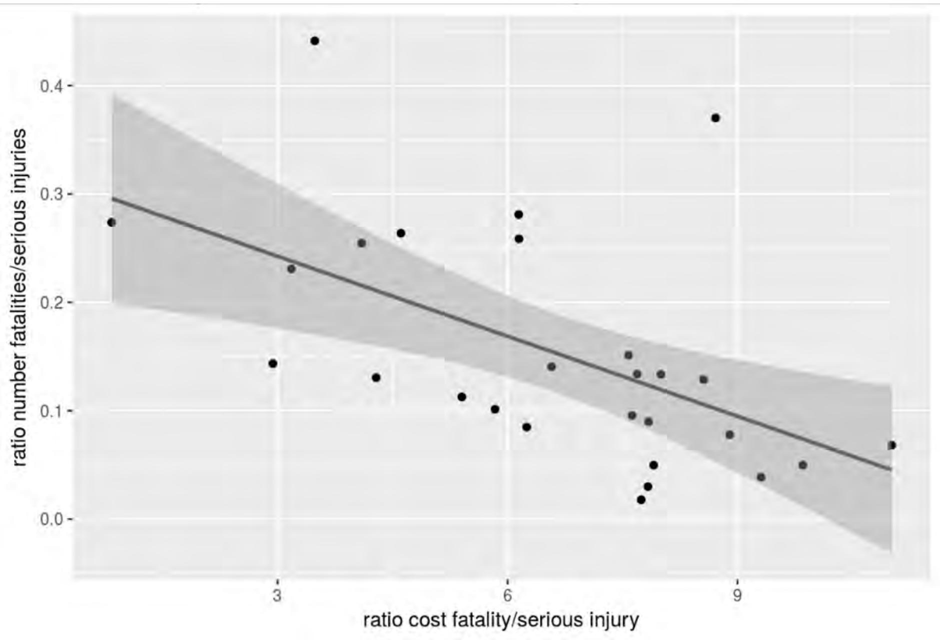

Figure 3.7: Relation between the ratio of number of fatalities and serious injuries and the ratio of costs per fatality and costs per serious injury (R^2=0.2996; F(1,25)=10.69; p=0.003).

3.3.3. Total costs

The total costs of road crashes as a percentage of GDP show also large variability, with a range from 0.4% to 4.1% (Figure 3.8). In addition to differences in methods used to estimate costs per casualty (discussed above), two other factors could potentially explain this variation. Firstly, it may reflect differences in road safety levels. Evidently, a better road safety performance should ceteris paribus result in lower road crash costs. However, road safety performance cannot explain the full variation as shown by Figure 3.9. Only a weak positive relation between mortality rate and costs as a percentage of GDP (statistically significant at the 10% confidence level) is found (R^2=0.122, F(1,28)=3.89; p=0.59).

Secondly, differences in the methodology that is applied to calculate total costs can explain variation in costs. In addition to the differences in methods to estimate costs per casualty (discussed above), this concerns in particular the extent to which all severity levels have been included in total costs and the extent to which a correction is made for underreporting. Concerning severity levels, all countries include fatalities, serious injuries and slight injuries in the estimate of total costs, but PDO crashes are not included in 44% of the countries (N=29). Exclusion of PDO crashes can result in a considerable underestimation of total costs: PDO crashes have a very significant weight in total costs, up to more than 50% for countries taking into account PDO crashes (Figure 3.10).

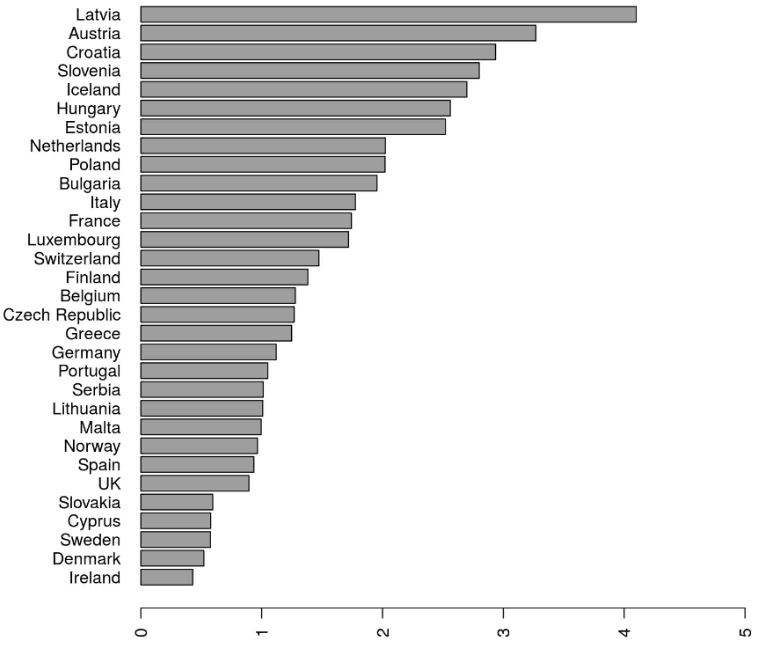

Figure 3.8: Total costs of road crashes as percentage of GDP.

Figure 3.10 also shows that injuries have a major share in total costs in most countries. The share of injuries is on average 2.4 times higher than the share of fatalities in total costs. Although the value of a fatality is much higher than the value of a serious or slight injury, the much higher number of injuries results in them having a relatively high share in the total costs in most countries. However, the distribution of costs over severity levels differs considerably between countries, even between countries that include all severity levels. For countries having information on all severity levels, the costs of fatalities account for 7.4% to 55% of the total costs, serious injuries account for 14% to 77%, slight injuries account for 1.9% to 34% and PDO crashes account for 2.0% to 55%. Such variations are explained partly, as discussed above, by variations in reporting rates at each severity level (few countries correct for underreporting of casualties or crashes in their estimates of total costs for instance).

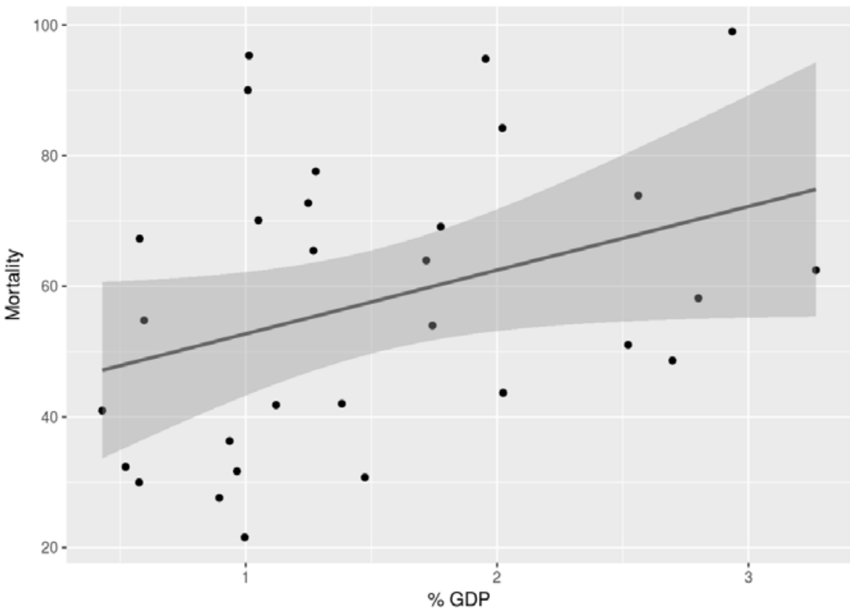

Figure 3.9: Relation between mortality rate (number of fatalities per million inhabitants) and costs of road crashes as percentage of GDP.

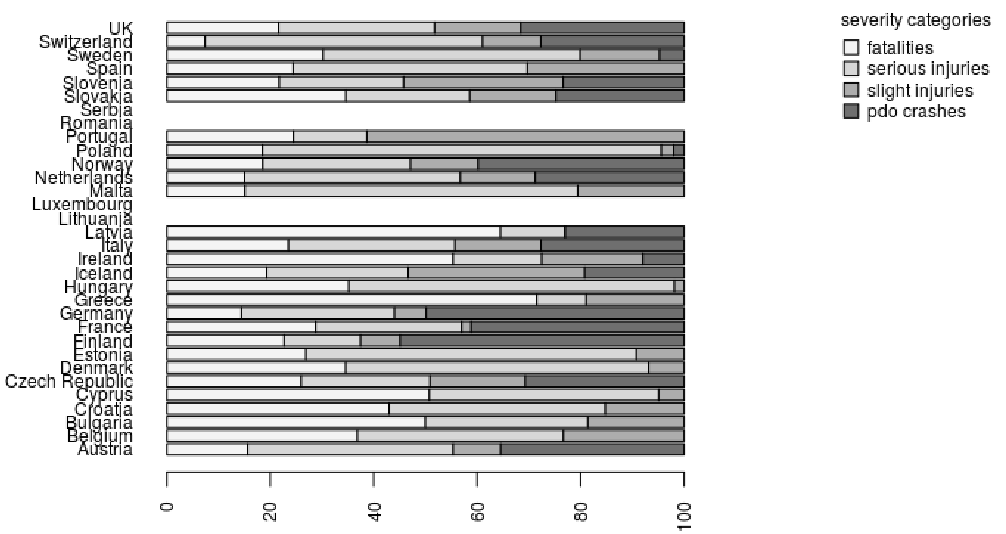

Figure 3.10: Share of fatalities, serious and slight injuries and PDO crashes in total costs.

3.4. Discussion

Our study shows that the official national estimates of road crashes found in European countries vary widely. This in line with the results of previous reviews of road crash costs, which are summarized in Table 3.2 (including this study). Previous studies found ranges of total costs (as percentage of GDP) which are quite similar to the range we found but including different countries with other valuation methods. Previous studies also found wide ranges of costs per fatality, with the highest value 3.9 to 20.5 times higher than the lowest value. In all of these studies the variation in cost estimates is largely explained by differences in methodologies, particularly concerning methods to estimate human costs, which is in line with the present results. Omission of unreported crashes and casualties further contributes to differences in estimates of total costs and, moreover, results in substantial underestimation of total costs, which is not noticed in previous studies.

Table 3.2: Overview of reviews of road crash costs.

Study	**Number of countries**	**Regions/countries**	**%GDP**	**Costs per fatality**	
				Range	*Ratio highest/lowest value*
Alfaro et al. (1994)	14	Europe	-	0.1-1.5 million ECU (1990)	11.2
Elvik (1995)	20	Europe (15), other (5)	-	0.9-17.8 million NOK (1991)	20.5
Elvik (2000)	11	EU (6), other (5)	1.3-5.7	-	-
Trawen et al. (2002)	11	EU (8), US, AU, NZ	-	0.9-3.6 million USD (1999)	3.9
Wijnen & Stipdonk (2016)	10	EU (6), AU, NZ, Singapore, US	0.5-6.0	1.4-9.5 million USD (2012)	6.8
Wijnen et al. (2017)	31	EU	0.4-4.1	0.7-3.0 million EUR (2015)	4.2

Human costs are much higher in countries that use on the willingness to pay approach. Values based on compensation payments appear to be much lower, as these are based on the common practices and judgements of organizations that determine the size of the compensation (e.g. law courts, insurance companies, governments) instead of risk valuations of the individuals involved. Countries that solely rely on the human capital approach have lower values because the production and consumption indicators used in this approach do not capture immaterial costs. These differences particularly affect the costs of a fatality, because human cost have a major share in total costs per fatality (54% to 94%). However, variation in the costs per fatality is not only related to the methodological approach (WTP or other methods), as also WTP estimates vary across countries. This is in line with literature on the VOSL (Value Of a Statistical Life). Several explanations for variation in VOSLs were found in meta-analyses

(Lindhjem et al., 2011; De Blaeij et al., 2003; Miller, 2000), including the type of WTP method (stated versus revealed preferences), the initial risk level, the size of the risk change that is evaluated, the economic welfare level and the characteristics of the mortality risk (e.g. public versus private risk). Hauer (2011) argues that variation in VOSL estimates is inherent to challenges related to the WTP elicitation methods, for example people's ability to understand small risks and to state their preferences related to those risks. The variation in the human costs of a fatality in our study is not as wide as the variation found in this literature. This is partly explained by the fact that several countries use standard European values. In addition, the people who decide on the official national values, who may be researchers or policy makers, usually can choose from a range of values. They may tend to choose conservative values (as was the case in the Netherlands for example; Wijnen et al., 2009), values that are in the same order of magnitude as the values used in other countries or standardized European values.

If our results are compared with the first European review of road crash costs in 14 European countries (Alfaro et al., 1994), the costs per fatality have converged even though we included more than twice as many countries: the highest value was 11.2 times higher than the lowest in 1994 whereas this ratio is 4.2 in 2015. Apparently, some convergence of methods used to estimate costs per fatality has taken place. However, the range of costs of a serious injury has become much wider: in the COST313 study the highest value was 11 times higher than the lowest (129,0280 versus 11,506 ECU, 1990), whereas in our study this ratio in 34 (€28,000-€959,000, 2015).[12] This is likely to be explained by the fact that we have included more countries that apply different and more heterogeneous definitions of a serious injury and/or different methods to estimate costs of injuries.

We have expressed total road crash costs as a proportion of GDP, which is common practice in international reviews of total road crash costs (Wijnen & Stipdonk, 2016; Elvik, 2000). This enables comparing the costs across countries, as differences in population size and economic performance are accounted for by using GDP as a denominator. However, the proportion of GDP should by no means be interpreted as the impact of road crashes on GDP. Human cost are intangible costs, which are not related to the measurement of income and production at which GDP is aimed. Moreover, road crashes could contribute positively to GDP, because crashes result in production in certain economic sectors such as health care and vehicle repair. GDP is a different concept from the concepts used in welfare economic theory which is the basis for cost-benefit analysis and (thus) for road crash costing. From the welfare economic perspective, costs are related mostly to the immaterial loss of welfare, or loss of quality of life associated with fatalities and injuries. In addition, resources that are used to repair damage are treated as costs in welfare economic theory. This contrasts with the GDP perspective, where using resources for production, also if this is aimed at repairing damage, contributes positively to economic welfare. Moreover, immaterial losses are not included in GDP.

[12] The COST313 values only include casualty-related costs (medical costs, production loss and human costs) whereas our estimates also include crash-related costs (property damage and administrative costs). This does not have much influence on the comparison, because crash-related costs have a minor share (4.1%) in total costs per serious injury.

Our analysis shows that the costs of road crashes vary widely across European countries, and that the differences are mainly explained by methodological differences. These differences hinder making sound international comparisons of road crash costs and using costs as a road safety indicator, as different costs represent differences in measurement more than difference in road safety performance. Moreover, it could distort road safety investments at the international level towards countries where costs per casualty are higher (and thus the benefits of these investments are assumed to be higher). For example, cost-benefit analysis of the implementation of European vehicle legislation would require a common value. Using different values could lead to erroneous conclusions about the economic return of such interventions for the different countries, if those differences are related to different valuation methods. For these purposes, harmonization of road crash costs estimates is needed.

3.5. Conclusions

There are large differences in official estimates of road crash costs in European countries. Total costs range from 0.4% to 4.1% of GDP and cost per fatality from €0.7 million to €3.0 million (2015, adjusted for PPP). Cost per serious injury range from 2.5% to 34.0% of the costs per fatality, and the costs per slight injury from 0.03% to 4.2% of the costs per fatality. The differences are largely explained by differences in methodologies, in particular whether or not a willingness to pay method is applied to estimate human costs, differences in costs components that are included, different definitions of serious and slight injuries and differences in reporting rates of crashes and injuries. The fact that underreporting is not taken into account in cost estimates in most countries, implies a serious underestimation of total costs in these countries. Moreover, several countries do not include property damage only crashes in total costs, implying a further underestimation of total costs.

The methodological differences in cost estimates are a serious obstacle when decisions on countermeasures have to be made at a supranational level or when international comparisons and benchmarking are needed. For these purposes developing harmonized European cost estimates is recommended. In addition, future national road crash costs studies could concentrate on applying international recommended methods (in particular WTP methods), on including all relevant cost components and on taking into account underreporting and PDO crashes, in order to achieve more harmonization.

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4. Socio-economic costs of road crashes in middle-income countries: applying a hybrid approach to Kazakhstan

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Abstract

Information about road crash costs is a valuable input for road safety policy making and it is essential for conducting cost-benefit analysis of road safety interventions. This paper presents a methodology for assessing the socio-economic costs of road crashes as well as an estimate of the volume of these costs in Kazakhstan. Five costs components have been taken into account: medical costs, production loss, human costs, vehicle damage and administrative costs. A hybrid methodological approach has been used, which implies that three different types of methods have been applied to capture all costs: the human capital method (production loss), willingness to pay (human costs) and restitution costs method (other components). Input data are retrieved from existing databases from a variety of road safety stakeholders and other organizations. A household survey was conducted to collect additional information, including the willingness to pay for fatal crash risk reductions. Remaining data gaps have been bridged by using data from other countries. The socio-economic costs of road crashes in Kazakhstan are estimated at $6.8 billion in 2012, which corresponds to 3.3% of GDP. Human costs account for 81% of the total costs, vehicle damage for 11% and production loss for 6%. Administrative and medical costs are relatively very small cost components. More than half of the costs is related to injuries, while fatalities account for about a third of the total costs and property damage only accounts for approximately 10%.

Keywords: costs, road accidents, human capital, willingness to pay, Kazakhstan

4.1. Introduction

Besides having a huge emotional impact on the quality of life, road crashes also pose a very significant socio-economic burden (Wijnen & Stipdonk, 2016; Elvik, 2000). Several costs result from road crashes, such as medical costs, loss of productive capacity, property damage, administrative costs and human costs (loss of quality of life and life years). Information on these costs can provide valuable input when a government must set its policy priorities and justify why it wishes to invest (more) in road safety (Wijnen & Stipdonk, 2016). Moreover, this information is needed for conducting cost-benefit analysis of road safety investments and other investments which affect road safety (Wijnen et al., 2019; Boardman et al., 2011). Cost-benefit analyses are commonly used to assess whether (road safety) investments are economically viable and to prioritize road safety investments on the basis of socio-economic profitability (Jones et al., 2014). In a cost-benefit analysis, the costs per casualty or per crash are required in order to monetize road safety impacts on the basis of road crash cost savings. Furthermore, the socio-economic costs of road crashes are considered to be an important outcome indicator for road safety management (Bliss & Breene, 2009; Wegman et al., 2009). This outcome indicator is frequently used in international reports on road safety performance in individual countries (ITF, 2017; WHO, 2015). In addition, cost information can be used to compare the economic burden of road crashes to the economic burden of other policy issues such as congestion, environmental pollution or different types of accidents and injuries (Wijnen et al., 2009).

Recent international reviews show that assessments of road crash costs have been conducted in a large number of high-income countries. For example, the socio-economic costs of road crashes have been estimated in thirty-one European countries (Wijnen et al., 2019), most of which (thirty) are high-income countries. Moreover, high-income countries in other parts of the world, such as Australia, New Zealand, Singapore and the United States have also assessed these costs (Wijnen & Stipdonk, 2016). The reviews show that methodologies differ across countries, the most debated issue being whether or not a willingness to pay method should be applied. Nowadays, the majority of high-income countries has adopted the willingness to pay approach, in combination with other valuation methods.

In contrast, the number of road crash cost studies in middle-income countries is limited (Wijnen & Stipdonk, 2016), although recent studies have been conducted in Egypt (Abdallah et al., 2016), Iran (Ahadi et al., 2015; Ainy et al., 2014) and Sudan (Mofadal & Kanitpong, 2016). In these studies, either the human capital method (Ahadi et al., 2015; Mofadal & Kanitpong, 2016) or the willingness-to pay method (Abdallah et al., 2016; Ainy et al., 2014) has been applied. However, to capture all of the cost components a combination of methods is required as these methods are aimed at different cost components (Wijnen et al., 2019; Alfaro et al., 2014). This paper presents an estimation of the socio-economic costs of road crashes in Kazakhstan using a hybrid methodological approach aimed at including all relevant socio-economic costs, both tangible and intangible, which has not been applied in middle-income countries before.

Kazakhstan is an upper middle-income country which has experienced rapid economic growth since the beginning of this century (IMF, 2018). However, road safety performance is still quite poor in Kazakhstan. The World Health Organization (WHO, 2015) estimated the mortality rate (number of road fatalities per 100,000 people) to be 24.2 in 2013, which is above the average number for middle-income countries (18.4 in 2013) and much higher than the mortality rate in high-income countries (9.2). Just as is often the case in other low- and middle-income countries, estimates of the costs of road crashes are not available in Kazakhstan, which presents an impediment for developing cost-effective road safety strategies and for spending the budgets made available efficiently.

The paper is structured as follows. The next section presents the hybrid methodology that has been applied to estimate the socio-economic costs of road crashes in Kazakhstan. Section 4.3 describes the various types of data sources that have been used to make the cost calculations. A more detailed discussion of the input data and methodology is provided in Section 4.4 (numbers of road casualties and crashes) and in Section 4.5 (method and data per cost element). The resulting costs are presented in Section 4.6, followed by a discussion (Section 4.7) and subsequently conclusions are drawn in Section 4.8.

4.2. Methodology

The costs of road crashes in Kazakhstan are viewed from a welfare economic perspective. According to welfare economic theory, the loss of welfare, which is the basis for cost-benefit analysis (Boardman et al., 2011; Johansson, 1991), is related to usage of scarce resources such as human resources (labour) and capital as well as to intangible issues such as loss of quality of life. The net costs for society are calculated, regardless of whom bears the costs, which implies that financial transactions which do not represent a welfare loss are not included. Several examples are taxes and fines; on the one hand, these are revenues for government bodies, but on the other hand, they are expenditures for citizens and therefore, no net social cost occurs. Such money transfers do not represent a loss of welfare, and as a result, they are not included in the cost assessment.

Five types of welfare impacts, or socio-economic cost categories, are included following best practices in high-income countries (Wijnen & Stipdonk, 2016; Wijnen et al., 2019) and international guidelines (Alfaro et al., 1994; BRS & TRL, 2003):[13]

- Medical costs: the costs of medical treatment and rehabilitation from injuries resulting from road crashes
- Production loss: loss of production and consumption due to the loss of human capacities
- Human costs: loss of quality of life and life years
- Property damage: damage to vehicles, roads, roadside objects and freight
- Administrative costs: costs of police and other emergency services, insurance and legal costs.

A distinction can be made between the costs related to injuries and the costs related to crashes. Medical costs, production loss and human costs are related to injuries, whereas property damage and administrative costs are related to crashes (Figure 4.1).

[13] A category 'other costs' can be added, which includes congestion costs and costs of vehicle unavailability, among others [3]. These other costs are known to be relatively small [1] and for that reason they have not been included.

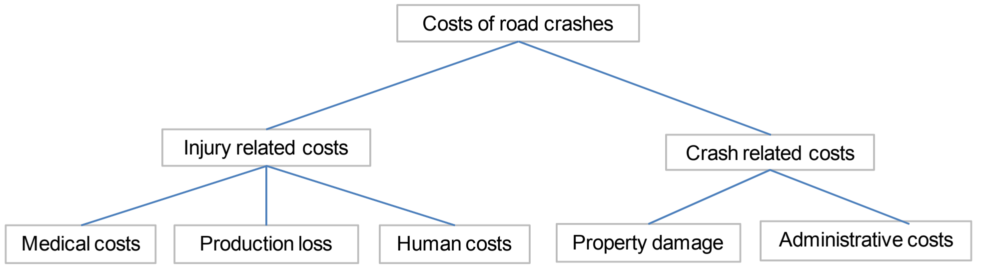

Figure 4.1: Road crash cost components, based on BRS & TRL 2003 and Alfaro et al. 1994.

Note that human costs are intangible costs, which are not reflected by market transactions and market prices. According to economic welfare theory, human costs should be included in road crash studies in order to reflect the full impact of road crashes on socio-economic welfare.

A hybrid methodological approach has been applied, based on best practices in high-income countries (Wijnen & Stipdonk, 2016; Wijnen et al., 2019), international guidelines (Alfaro et al., 1994; BRS & TRL, 2003) and economic theory (Boardman et al., 2011; Freeman et al., 2014). This implies that three different types of methods are applied so that all of the relevant socio-economic costs can be included (Wijnen et al., 2019; Alfaro et al., 1994):

1. Restitution costs approach: this approach concentrates on the costs of resources that are needed to restore those who have suffered from road crashes, as well as their relatives and friends, to the previous situation as these costs would not have occurred if they had not been involved in a road crash.
2. Human capital approach: in this approach the societal value of the loss of productive capacities of road casualties is measured.
3. Willingness-to-pay (WTP) approach: costs are estimated on the basis of the amount individuals are willing to pay for reducing risks.

The restitution costs approach is aimed at estimating medical costs, property damage and administrative costs (Wijnen et al., 2019; Alfaro et al., 1994). This means that the direct costs of using resources (labour, equipment, etc.) for medical treatment, vehicle repair, emergency services, legal issues and insurance administration are estimated. In most cases, market prices are used to estimate these costs, assuming that market prices reflect the societal value of the resources.

The human capital approach is used to calculate production loss. In this approach, the loss of productive capacities related to road casualties is valued (Freeman et al., 2014). It is common international practice in road crash cost studies to calculate potential production loss (Wijnen & Stipdonk, 2016; Wijnen et al., 2019), which means that the value of the goods or services that someone could have produced, if he or she was not killed or injured, is calculated, regardless of whether the person was actually (full-time) employed. Potential production loss accounts for the fact that the time loss suffered by the unemployed also has a socio-economic value. The unemployed may be productive in terms of household work, child care or voluntary work. A distinction can be made between gross production loss, which includes consumption loss, and net production loss which excludes consumption loss (Wijnen et al., 2009). Gross production loss is measured by the (lost) value added or income that an employed person produces. Since part of this value added is used for paying wages, which in turn are used for consumption expenditure, consumption is implicitly included in gross production.

To estimate human costs, the WTP approach is applied as this is generally regarded as the most appropriate method for calculating human costs (Wijnen et al., 2019; Bahamonde-Birke et al., 2015; Milligan et al., 2014; Alfaro et al., 1994). In the WTP approach, people are directly or indirectly asked how much money they are willing to pay for a risk reduction which enables the 'Value of a Statistical Life' (VSL) to be determined. The VSL does not reflect the value of individual lives, but statistical lives saved, since it is based on the willingness to pay for reducing the probability of dying in a road crash. The VSL includes human costs and consumption loss (Wijnen et al., 2009). Consequently, human costs are calculated by deducting consumption loss from the VSL. This is also done to avoid double counting consumption loss, when the concept of gross production loss has been used.

A bottom-up approach is applied to calculate the size of each cost item: the costs per casualty or crash (unit cost) are determined and multiplied by the corresponding number of casualties or crashes in order to calculate the total costs per item. The only exception that is made is when calculating the costs of insurance: total costs are directly estimated and costs per casualty and crash are derived from the total costs (top-down).

All the costs have been estimated for the year 2012 and these have been expressed in the price level of 2012. The cost data from other years have been converted into the 2012 price level by using consumer price indexes as published by the World Bank (World Bank, 2017a) and the amounts expressed in local currency are converted into US dollars, using an exchange rate of 149.11 KZT per US$ (World Bank, 2017a).

4.3. Data sources

Data on a variety of issues is needed for the assessment of road crash costs, including data on road casualties and crashes, medical treatment, labour market, damage to vehicles, police costs related to road crashes, insurance data and people's willingness to pay for crash risk reductions. To obtain the required data for the case of Kazakhstan, several types of data sources are utilized. Firstly, databases of several governmental institutions and other organizations are used, including the General Prosecutor's Office, Ministry of Interior, Administrative Police Committee, Agency of Statistics, Ministry of Economy and Budget Planning, Ministry of Health, Ministry of Labor and insurance companies.

Secondly, a household survey was conducted in March 2014 by Sange Research Centre to collect data that were not included in the databases of these organizations. Face-to-face interviews were held with a representative sample of the Kazakh population, stratified by region, age, gender and ethnicity. A combination of geographical, random route and quota sampling was applied. Quotas for region, age, sex, ethnicity were defined based on national demographic data. Regions were assigned to interviewers and each interviewer received fixed quotas for their region to interview respondents with certain age, sex and ethnicity characteristics. Households in each region were selected by dividing settlements on a map into 10 to 20 squares (depending on the size of the settlement). Each third square was selected for the survey and every third household was selected. If no respondent was available at the household, the interviewer went to the neighbouring household.

The sample included 1,050 respondents aged 18 years or older. In addition, 105 people were interviewed in shopping centres after the household survey was conducted, in order to make allowance for the low proportion of high-income households in the household survey. In addition, 210 people were interviewed in car repair garages to include more people who had been involved in a road crash, which were (only) used to estimate property damage by crash severity more accurately. Tables 4.1 and 4.2 present the number of respondents by region and by age, gender and ethnicity respectively, as well as comparisons with the total population.

The survey comprised three parts:

1. The willingness to pay for improved road safety. This part includes questions on the respondent's risk understanding and on the willingness to pay for risk reductions in two scenarios (explained in more detail in Section 4.5).
2. People's involvement in road crashes and the consequences of those crashes in terms of injuries and car damage. This section includes questions on how often respondents were involved in a crash, the severity of the injuries resulting from these crashes, the extent of car damage, police attendance at the crash location, car insurances and payments received from insurance companies.
3. General question about the respondent, such as age, gender, income and education.

The full questionnaire is found in Appendix 1.

Thirdly, in some cases a value transfer approach is used, which means that data or results of road crash cost studies in other countries are applied to the case of Kazakhstan. In particular, data from detailed road crash cost studies in high income countries that were included in a review conducted by Wijnen & Stipdonk (2016) are used. The data from other countries particularly concern the number of road casualties and crashes, the duration of hospitalization and the length of absence from work. Obviously, it is uncertain to what extent these data reflect the actual situation in Kazakhstan. However, given the fact that these data are not available in Kazakhstan, nor in other low- and middle-income countries, using data from high-income countries is considered to be the second-best option. Concerning unit costs, country-specific information for Kazakhstan was used for the calculation of each cost item. Appendix 2 contains an overview of the data from other countries that have been used in making the calculations.

Table 4.1: Number of respondents in the sample and total population by region.

Regions	Sample					Total population	
	Households	*Shopping centres*	*Car repair garages*	*Total*			
Akmola	44	4	9	57	4.2%	732,028	4.4%
Aktobe	51	5	10	67	4.9%	791,066	4.7%
Almaty region	98	10	20	127	9.3%	1,927,718	11.5%
Almaty city	116	12	23	151	11.1%	1,462,614	8.7%
Astana city	60	6	12	78	5.7%	760,541	4.5%
Atyrau	33	3	7	43	3.2%	549,091	3.3%
Batys	37	4	7	48	3.5%	615,068	3.7%
Jambyl	61	6	12	79	5.8%	1,062,843	6.3%
Karagandy	97	10	19	126	9.2%	1,360,312	8.1%
Kostanai	54	5	11	70	5.1%	879,699	5.2%
Kyzylorda	42	4	8	54	4.0%	719,795	4.3%
Mangistau	34	3	7	44	3.2%	556,754	3.3%
Ontustik	150	15	30	195	14.3%	2,650,187	15.8%
Pavlodar	51	5	10	66	4.8%	748,011	4.5%
Soltustik	33	3	7	43	3.2%	581,534	3.5%
Shygys	89	9	18	116	8.5%	1,394,164	8.3%
Total	1,050	105	210	1,365	100%	16,791,425	100%

Table 4.2: Percentual distribution of respondents in the sample and the general population over age groups, gender and ethnicities.

	Age group				Gender		Ethnicity		
	18-29	30-44	45-59	60+	men	women	Kazakh	Russian	Other
General population	31.2	30.1	24.2	14.5	48.3	51.7	65.5	21.5	13.0
Sample	31.3	30.2	24.2	14.4	48.3	51.7	64.9	22.0	13.1

4.4. Number of casualties and crashes

The number of road casualties and crashes (by severity) is a key input for road crash cost calculations. We distinguish between:

- Fatality: a person killed immediately or who has died within 30 days as a result of a road crash.
- Fatal crash: a crash resulting in at least one fatality.
- Serious injury: an injured person who has been treated in hospital requiring an overnight stay.
- Serious injury crash: a crash resulting in at least one serious injury (but no fatalities).
- Slight injury: a person who has been injured, but who has not been treated in hospital and who did not require an overnight stay.
- Slight injury crash: a crash resulting in at least one slight injury (but no fatalities or serious injuries).
- Property Damage Only (PDO) crash: a road crash causing damage to at least one vehicle, but no fatalities or injuries.

Additionally, the number of injuries resulting in a permanent disability and the number of slight injuries treated at the emergency department of hospitals are used to calculate production loss and hospital emergency treatment respectively.

The number of police-reported fatalities has been taken from the official statistics of the General Prosecutor's Office of Kazakhstan, which shows that there were 3,022 road fatalities in Kazakhstan in 2012. The WHO (2015) classifies Kazakhstan as a country with a good road fatality registration (at least 80% completeness) and therefore, this number is assumed to closely reflect the actual number of fatalities. The number of reported serious injuries was 25,461 in 2012 according to the statistics of the Agency of Statistics which have been based on hospital data. The degree of underreporting is not known. The ratio of the reported number of serious injuries to fatalities is 8.4:1 in Kazakhstan. This is at the lower end of the range of these ratios in other countries, where the ratio of the number serious injuries to fatalities (both corrected for underreporting) is between 6:1 and 26:1 (with the ratio in the UK as an outlier, 49:1, see Appendix 2). Therefore, we consider the number of serious injuries as reported by the Agency of Statistics as a plausible, but probably conservative, figure.

Statistics on the number of slight injuries and the number of crashes by severity are not available in Kazakhstan. We use the survey results to (roughly) estimate these numbers. Respondents (N=1,155) were asked if they, or their household members, had been involved in a road crash during the past three years and they were subsequently asked what the degree of their injury severity was in their two most recent crashes in that period. The survey revealed information on 319 injury crashes in which the respondents, or their household members, were involved. Table 4.3 shows the number of injuries that have resulted from these crashes by severity. The number of slight injuries reported by the respondents is 6.0 times higher than the number of serious injuries. This is consistent with the ratio found in other countries where this ratio ranges from 1:5 to 1:15 (see Appendix 2). We have applied a ratio of 1:6.0 to estimate the number of slight injuries at roughly 153,000.

Table 4.3: Number of injuries due to the two most recent injury crashes respondents were involved in in three years.

Injury severity	**Number of injuries**	**Proportion**
Slight, no hospital treatment required	194	61%
Slight, hospital treatment (but no overnight stay required in hospital)	69	22%
Serious	44	14%
Fatal injury	12	4%
Total	319	100%

The number of permanently-disabled casualties was determined by using data received from a large hospital. The data show that 3% of the road casualties treated in this hospital were 'extremely seriously' injured (20 out of the 670 casualties in 2012). We have applied this proportion to the number of serious injuries in Kazakhstan as a rough estimate, which is probably conservative because other casualties might also be classified as being lifelong disabled.

The number of casualties treated in the emergency department of hospitals has been estimated using survey results (Table 4.3). The survey shows that 26% of the slight injuries (69 out of

263) were treated in hospital (without requiring an overnight stay). Applying this proportion to the estimated number of slight injuries (180,000) results in 40,000 casualties treated in the emergency department of a hospital.

Information on the number of road crashes is not available in Kazakhstan. We have estimated the number of injury crashes (by severity) using the number of casualties in Kazakhstan and the ratio of the number of casualties to the number of crashes in other countries. Note that this ratio depends on country-specific crash characteristics, such as the occurrence of specific crash types (e.g. single vehicle crashes) and the vehicle occupancy rate. Since data regarding these characteristics are lacking in Kazakhstan, it is unknown which country reflects the situation in Kazakhstan most appropriately. Therefore, we have applied the unweighted average of the ratios in other countries to estimate the number of crashes in Kazakhstan. These average ratios are 1.08 for fatalities (1.08 fatality per fatal crash), 1.17 for serious injuries, and 1.32 for slight injuries (see Appendix 2). Applying these ratios to the number of casualties in Kazakhstan results in 2,800 fatal crashes, 22,000 serious injury crashes and 137,000 slight injury crashes in Kazakhstan.

A (rough) estimate of the number of PDO crashes in Kazakhstan has been made using the information available from other countries, where the ratio of the number of PDO crashes to the number of serious injuries ranges from 22:1 to 55:1 (and 165:1 in Austria as an outlier, see Appendix 2). We assume that the ratio of PDO crashes to the number of serious injuries is at least 22:1 in Kazakhstan, resulting in 560,000 PDO crashes as a rough and probably conservative estimate.

Table 4.4 summarizes the number of casualties and crashes in Kazakhstan.

Table 4.4: Number of road casualties and crashes used in the crash-cost calculations.

Severity category	**Data source**	**Number**
Number of fatalities	General Prosecutor's Office, Agency of Statistics (age distribution)	3,022
Number of fatal crashes	Value transfer (ratio fatal crashes : fatalities in other countries)	2,800
Number of serious (hospitalized) injuries	Agency of Statistics / Ministry of Health	25,461
Number of permanently-disabled injuries	Catastrophes' Medical Centre	784
Number of serious injury crashes	Value transfer (ratio serious injury crashes: serious injuries in other countries)	22,000
Number of slight injuries	Survey (ratio slight/serious injuries)	153,000
Number of casualties treated in the hospital's emergency department	Survey	40,000
Number of slight injury crashes	Value transfer (ratio slight injury crashes : slight injuries in other countries)	137,000
Number of PDO crashes	Value transfer (ratio PDO crashes/serious injuries in other countries)	560,000

4.5. Calculation method and data per cost component

4.5.1. Medical costs

The following medical cost items have been included:

- Transportation of casualties to hospital
- Treatment received in the emergency department of a hospital
- In-patient hospital treatment (requiring an overnight stay)
- Rehabilitation.

In addition, funeral costs have been included as a medical cost item, although these can also be classified as 'other costs' (Wijnen et al., 2019). It is not uncommon, however, to include funeral costs along with the medical costs (BRS & TRL, 2003) and we have followed that same practice here. The costs of out-patient treatment (other than treatment in the emergency department) and non-hospital treatment (e.g. by a general practitioner) have not been included because data on these costs are not available in Kazakhstan. These costs are assumed to be relatively small compared to the costs of hospitalization.

Casualty transportation costs are calculated on the basis of the number of casualties transported to hospital by ambulance and the average costs per ambulance ride. Similarly, the costs of emergency treatment, in-patient hospital treatment and rehabilitation are calculated by using the number of casualties who have received a particular treatment and the average costs corresponding to each treatment (unit costs). Unit costs of in-patient hospital treatment and rehabilitation are calculated by using the average number of days that treatment has been received and the costs per day.

Data on unit costs, the average duration of hospital treatment and rehabilitation, as well as data relating to the number of ambulance trips for five regions in Kazakhstan (out of 12 regions) were provided by the Ministry of Health, which retrieved the data from hospitals. Average costs weighted by population size are used and the costs are adjusted to allow for regional price differences, using consumer price indices from the Agency of Statistics. The total number of ambulance rides is estimated by multiplying the ratio of ambulance rides to the number of reported hospitalized injuries in the five regions by the total number of reported hospitalized injuries in Kazakhstan. The proportion of fatalities treated in hospital, and the average duration of this treatment, are estimated by using results from studies in other countries (see Appendix 2).

Funeral costs are calculated by taking the difference between the actual costs of a funeral and the future costs of a funeral if the person had not been killed in a road crash. The costs of a funeral are based on the results of a survey carried out by a news website (Total, 2012). The future costs are calculated as the present value of the costs of a funeral in a future year, which is determined using data from the Agency of Statistics on the age and gender of each fatality, and the life expectancy by age and gender. The future costs are discounted by using a social discount rate. The discount rate is set at 8% based on a review of social discount rates used in cost-benefit analyses, which shows that discount rates range from 3% to 7% in high-income countries and 8% to 12% in low- and middle-income countries (Zhuang et al., 2007).

Table 4.5 summarizes the input values used to calculate medical costs.

Table 4.5: Input data for calculating medical costs.

Indicator	**Source**	**Value**
Yearly number of ambulance trips	Ministry of Health	53,000
Cost per ambulance trip	Ministry of Health	$30
Average duration of hospitalization per serious injury (days)	Ministry of Health	18
Average costs of in-patient hospital treatment per casualty per day	Ministry of Health	$70
Average costs of treatment at emergency department	Ministry of Health	$21
Average number of rehabilitation days per casualty	Ministry of Health	11
Average costs of rehabilitation per casualty per day	Ministry of Health	$60
Proportion fatalities treated in hospital	Other countries	27%
Average duration of hospitalization per hospitalized fatality (days)	Other countries	5
Cost per funeral	Total, 2012	$246
Social discount rate	Zhuang et al., 2007	8%

4.5.2. Production loss

Production loss results from the fact that road casualties can no longer work, permanently (fatalities, severe injuries) or temporarily (injuries). Following international best practices, we have used the concept of gross potential production loss which, as discussed above, includes consumption loss. Gross production loss has been calculated by using the number of fatalities and serious injuries, the average length of time a person cannot work due to the crash and wages (as an indicator of the value of gross production per unit of time). For fatalities and permanently disabled, the duration of inability to work is the number of productive life years remaining. This period is calculated by using data from the Agency of Statistics on the age of those who have suffered serious injuries and fatalities, the age at which people enter the labour market (by gender and education level) and life expectancy by (age and gender). The education level distribution of casualties is assumed to be equal to the distribution for the entire population. In regard to those who have been injured and who are not permanently disabled, the duration of absence from work is set at 30 days after leaving hospital based on a Russian road crash cost (Ministry of Transport Russian Federation, 2001) and for slight injuries at 7 days (the average of other countries, see Appendix 2). Average gross yearly wages are used: $10,459 (men) and $7,275 (women) (Source: Agency of Statistics). Future production has been discounted by using the 8% discount rate discussed above.

In addition, there are costs suffered by employers who must recruit and train new employees to (temporarily) replace injured employees. Data on these ‘friction costs’ were not available and for that reason these costs have not been included. These costs are known to be relatively very small (Wijnen & Stipdonk, 2016).

4.5.3. Human costs

To estimate the value of a statistical life (VSL) in Kazakhstan, from which the human costs are derived, a stated preference survey was conducted among a representative sample of the Kazakh population aimed at determining the willingness to pay for a fatal crash risk reduction. Stated preference methods are very commonly used to derive the VSL in the context of road safety (Lindhjem et al,. 2011; De Blaeij et al., 2003). Particularly in Europe they are often preferred above revealed preference methods, which derive the value of risk reductions from actual behaviour, such as purchasing behaviour regarding safety provisions (e.g. airbags). One reason for this is that stated preference methods have a broader applicability as they are not dependent on information regarding actual (purchasing) behaviour. Furthermore, consumers usually are not (fully) aware of the risk reduction resulting from their (purchasing) behaviour, and stated preference methods allow to provide this information in order to help respondents in understanding the (small) risk reductions better (De Blaeij et al., 2003). On the other hand, stated preference methods are more prone to several types of bias related to using questionnaires, for example bias related to the hypothetical nature of the valuation questions (Bahamonde-Birke et al., 2015; De Blaeij, 2003).

A contingent valuation questionnaire design with two risk reduction scenarios was used. In the first scenario, respondents were asked to imagine that they travel once every month by car with a driver from their home town to a place at a distance of approximately 150 kilometres. Two cars are available with each having different risks of being killed in a crash (20:100,000 and 10:100,000 respectively). The respondents were asked to state the maximum amount that they would be willing to pay per round trip, which means every month, for traveling in the safer car by choosing an amount from a payment card that showed various amounts ranging from 100 to 2,500 KAZ (including the options ‘less than 100 KAZ’ and ‘more than 2,500 KAZ’). In the second scenario, respondents were asked to imagine that they move to a city because of their work (or to another city if they already live in a city). They could choose between two cities consisting of 300,000 inhabitants that are identical except with respect to the level of road safety (3 versus 6 fatalities each month) and the costs of traveling to and from their work by bus. Respondents were asked what would be the maximum amount that they would be willing to pay extra per month for traveling to/from their work in the safer city compared to the other city, using the same payment cards. The highest risk level in both scenarios reflects the actual average risk level in Kazakhstan. Payment cards have been used here because respondents may have difficulties when answering willing to pay questions. Most people are not used to stating amounts of money directly, particularly in cases which they are not familiar with, such as road safety risks and small risks (Bahamonde-Birke et al., 2015). On the other hand, payment cards are prone to bias related to the range of amounts shown on the cards (De Blaeij, 2003). To minimize such ‘range bias’, a large number of amounts (20) was shown covering a wide range.

Before answering the valuation questions, small risks were explained to the respondents and the respondents’ risk understanding was tested by using a grid boxes approach as applied by De Blaeij (2003) and Bhattacharya et al. (2007). The respondents were shown a paper with 100,000 grid boxes, of which 20 boxes were shaded, and then the reverse side of the paper was shown where the grid boxes were not visible. The respondents were told that the probability of dying in a road crash in a year is equal to the probability of touching a shaded box if he/she puts a needle in the paper, and that this is a chance of 20 out of 100,000. Next, a similar paper was shown, but this time 40 out of 100,000 grid boxes were shaded. Two questions on the relative size of the risks were asked in order to test the respondents’ understanding of small risks. Respondents who did not answer these questions correctly were excluded from the analysis.

In the first scenario (choice of car), respondents were willing to pay $7.3 on average to lower their yearly risk of being killed in a crash from 20:100,000 to 10:100,000, which translates into a VSL of $871,790. In the second scenario (choice of city) respondents were willing to pay $6.0 on average to lower the monthly number of fatalities by 3, which results in a VSL of $595,633. The lower WTP in the latter scenario might be explained by the fact that people are willing to pay more for the reduction of private risks (such as the risk of their car) than for public risks (for example, a safer road) (Svensson & Johansson, 2010).

As expected, the WTP is found to increase with income in both scenarios (Figure 4.2), which is consistent with findings in the literature on the relation between WTP for safety and income (Viscusi & Aldy, 2003). It reflects that people's budgets for safety expenditures increases with income. The WTP initially increases with age, and then it decreases from a certain age (inverted U-curve) in both scenarios (Figure 4.3). This is consistent with several studies on the relationship between WTP and age, although positive, negative or no significant relations have been found in the literature as well (Johansson. 2002).

The average VSL resulting from both scenarios ($733.711) has been applied in order to calculate the human costs. Consumption loss has been deducted for the VSL in order to determine the human costs. Consumption loss per fatality, by age and gender, has been calculated as the sum of the yearly household consumption per capita in all of the remaining life years if a person would not have been killed in a road crash, using data on the age of fatalities, life expectancy by age and the discount rate.

Value transfer has been used to estimate the human costs related to injuries. Studies on the willingness to pay for reducing serious and slight injury risk, relative to the willingness to pay for reducing fatal risk, have been conducted in Belgium (De Brabander, 2006), Sweden (Persson, 2004) and the UK (O'Reilly et al., 1994). Table 4.6 summarizes the results of these studies (the value of preventing a serious injury as a proportion of the VSL). The value for slight injuries in Belgium refers to casualties who have been treated in hospital and it is therefore not applicable to slight injuries as defined in this study (no overnight stay required in hospital). Based on the results of these studies, we have applied a value of 13% of the VSL for serious injuries and 1% of the VSL for slight injuries to estimate the human costs related to injuries. These values correspond to the recommendations made regarding the valuation of road injuries in several European projects (Bickel, 2006; ECMT, 1998). It is assumed that there is no consumption loss related to injuries, which implies that a correction for consumption loss (as was made with respect to fatalities) is not needed.

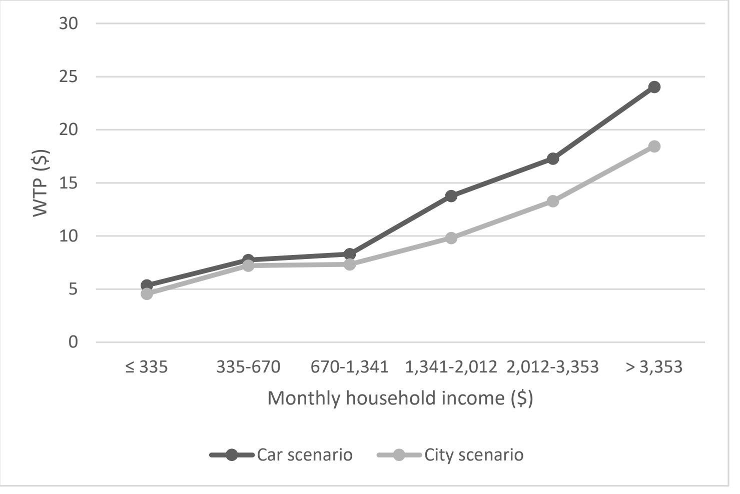

Figure 4.2: Relationship between willingness to pay and income ($).

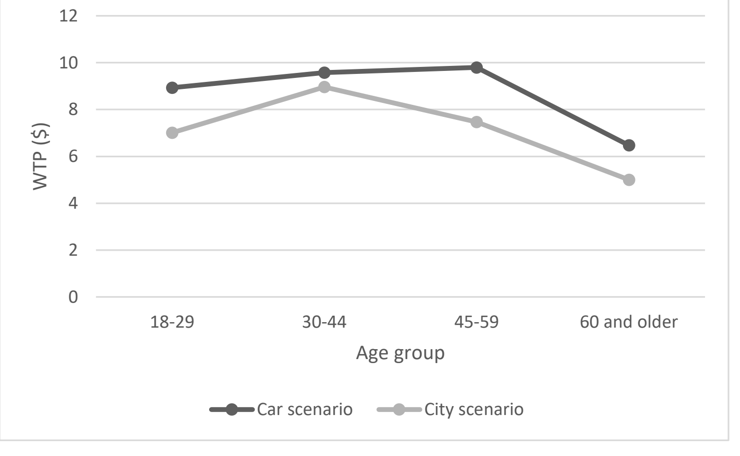

Figure 4.3: Relationship between willingness to pay and age.

Table 4.6: WTP values per injury as a proportion of the VSL.

Country	Serious injuries	Slight injuries
UK	10%	0.9%
Sweden	16%	1.5%
Belgium	7-85%	1.6%

4.5.4. Property damage

Damage to vehicles is calculated using the number of crashes (by severity), the number of damaged vehicles per crash and the average damage per vehicle. The survey included questions on the number of vehicles involved in the most recent and next most recent crash the respondent (or a household member) was involved in and the damage done to his/her car. Table 4.7 shows the average damage per car by crash severity. The average number of cars involved in a crash (all severities) was 2.1 (N=256).

Table 4.7: Average damage per car.

	Average damage per car	N
Fatal	404,692	7
Serious	114,373	38
Slight	82,122	223
PDO	73,970	271

Other property damage, such as damage to infrastructure, has not been included due to the lack of data. This damage is known to be very small compared to vehicle damage (Wijnen & Stipdonk, 2016).

4.5.5. Administrative costs

Police costs have been calculated on the basis of the number of crashes by severity, the proportion of crashes the police attends, the police time spent per crash and the average wage police officers receive. The survey showed that the proportion of police attendance ranged from 43% for PDO crashes (N=162) and 66% for slight injury crashes (N=172) to 91% for serious injury crashes (N=32). For fatal crashes 100% police attendance is assumed. Police time spent and the number of police officers attending a crash have been based on educated guesses using information provided by the Ministry of Interior and the General Prosecutor's Office (Table 4.8).

Table 4.8: Police time spent by severity of crash.

	Hours per crash	Number of policemen attending a crash	Total time spent (hours)
Fatal	4	6	24
Serious injury	3	4	12
Slight injury	2	3	6
PDO	1	2	2

Costs of other emergency services (mainly fire department services) are estimated as a proportion of police costs. This proportion depends, among others, on crash severity and wage differences between the police and other emergency service personnel. Since there is no data available on this in Kazakhstan, we have applied the unweighted average proportion found in other countries (70% of police costs, see Appendix 2) to estimate the costs of other emergency services in Kazakhstan.

Administrative costs of vehicle insurances have been estimated by using data concerning the income that all insurance companies in Kazakhstan receive from vehicle insurance premiums ($230 million; Source: National Bank of Kazakhstan) and the ratio of administrative costs to premium income as provided by two large insurance companies in Kazakhstan (0.4:1, average weighted by market share of the companies). A correction was made for the fact that 1.6% of the cases are related to other damage causes than road crashes, such as theft and vandalism, according to data provided by one of the insurance companies. This resulted in an estimate of the administrative costs that were related to vehicle insurance of $82 million.

4.6. Results

Table 4.9 presents the total costs by cost component and severity level. The total costs of road crashes are estimated at $6.8 billion in 2012, which corresponds to 3.3% of the GDP (GDP was $208 billion in 2012 (World Bank, 2017a)). Human costs are estimated at $5.5 million, and thus account for a large proportion of total costs (81.1%). Property damage (damage to cars) is the most important other cost component, having a share of 11.3% in total costs, while production loss accounts for 5.9% of total costs. Administrative costs and medical costs are relatively small cost components, accounting for 1.3% and 0.4% of the total costs, respectively.

More than half of the costs ($3.9 billion) is related to injuries. Fatalities account for about a third of the total costs, and PDO crashes for about 10%. The distribution of costs over severity categories differs between costs components: fatalities have a large share (71%) in production loss, whereas serious injuries account for a major part (74%) of the medical costs. PDO crashes have a share of 73% in both property damage and administrative costs.

Table 4.10 presents the costs per casualty and per PDO crash. The costs of a fatality are estimated at $764,000, the costs of a serious and slight injury at $101,000 and $8,000, respectively and the costs of a PDO crash at $12,000.

Table 4.9: Cost of road crashes in Kazakhstan in 2012 (million US$).

		Fatalities	**Serious injuries**	**Slight injuries**	**PDO**	**Total**
Medical costs	*Transportation costs*	0.0	0.6	1.0	-	1.6
	Hospital costs, in-patient	0.3	19.0	0.0	-	19.3
	Hospital costs, out-patient	0.0	0.0	0.8	-	0.8
	Rehabilitation costs	0.0	1.6	0.0	-	1.6
	Funeral costs	5.3	0.0	0.0	-	5.3
	Total medical costs	5.6	21.1	1.8	-	28.5
Production loss		285.1	93.3	22.1	-	400.6
Human costs		2,002.3	2,414.7	1,114.5	-	5,531.5
Vehicle damage		16.0	35.2	134.1	583.5	768.8
Administrative costs	*Police*	0.3	1.0	1.9	2.0	5.2
	Other emergency services	0.2	0.7	1.4	1.4	3.7
	Insurance costs	0.3	2.5	13.5	65.4	81.8
	Total administrative costs	0.8	4.2	16.8	68.8	90.7
Total		2,309.8	2,568.6	1,289.4	652.4	6,820.1

Table 4.10: Cost per casualty (1,000 US$).

	Fatality	**Serious injury**	**Slight injury**	**PDO crash**
Medical costs	1.8	0.8	0.01	-
Production loss	94.4	3.7	0.1	-
Human costs	662.6	94.8	7.3	-
Property damage	5.3	1.4	0.9	10.4
Administrative costs	0.3	0.2	0.1	1.2
Total	764	101	8	12

4.7. Discussion

The calculations show that road crashes pose a very considerable socio-economic burden in Kazakhstan, corresponding to 3.3% of GDP. The size of this burden is within the range found in other countries: recent reviews found costs of road crashes ranging from 0.4% to 4.1% of the GDP in Europe (Wijnen et al., 2019) and from 0.5% to 6.0% of the GDP worldwide (Wijnen & Stipdonk, 2016). However, the calculated estimate for Kazakhstan can be regarded as a lower limit of the costs due to the fact that the analysis concentrated on the most important cost items and it did not include several other, although minor, cost items such as legal costs, damage to infrastructure and traffic congestion costs. Moreover, the costs are likely to be underestimated because the number of reported fatalities and serious injuries were used. The actual numbers of fatalities and serious injuries are expected to be higher due to underreporting. As a consequence the number of slight injuries and PDO crashes is also conservative, as these numbers were determined using likely, but also conservative, ratios of the number of slight injuries and PDO crashes respectively to the number of reported serious injuries.

The VSL in Kazakhstan ($ 0.73 million) is relatively low compared to VSLs in other countries according to academic literature. Milligan et al. (2014) conducted a regression analysis using 308 VSL estimates. They developed value transfer functions for low- and middle-income countries (LMIC), high-income countries (HIC) and all countries, that specify the relationship between the VSL and GDP per capita. If the value transfer functions for LMIC and for all countries are applied to Kazakhstan, using a GDP per capita of $12,387 in Kazakhstan (World Bank, 2017a), this results in a VSL of $3.7 million and $3.5 million, respectively.[14] However, the VSL in Kazakhstan is in line with an international rule of thumb developed within the International Road Assessment Programme (McMahon & Dahdah, 2008). Based on a regression analysis using VSLs from 22 countries, they recommend using a VSL of 70 times the GDP per capita in economic appraisal of road infrastructure investments. Hence, this would result in a VSL of $0.87 million in Kazakhstan. A likely explanation, which could account for the fact that this rule of thumb resulted in a lower VSL compared to the value transfer developed by Milligan et al. (2014), is the fact that the regression analysis made by McMahon and Dahdah (2008) used a VSL that was officially determined by the government (e.g. for use in cost-benefit analysis). Milligan et al., on the other hand, used a VSL that was determined in academic studies. The official VSLs are lower in many countries, as the policy makers or researchers who decide on the official national values may tend to choose more conservative values (Wijnen et al., 2019).

A striking result of our study is the high proportion of human costs in the total costs. However, a high proportion of human costs is in line with results found in other countries that use a WTP approach. The WPT approach is known to result in much higher values than other valuation methods, such as methods that use compensation payments which are paid by insurance companies to casualties or their relatives (Wijnen & Stipdonk, 2016; Elvik, 2000; Elvik, 1995). Recent international reviews of road crash cost estimates report that human costs account for 34% to 91% (Wijnen et al., 2019) and 46% to 68% (Wijnen & Stipdonk, 2016) of total cost if a WTP is used.

It should be noted that ratio of the road crash costs to GDP (3.3%) should not be interpreted as the impact of crashes on GDP. GPD is only used to scale the cost and it is common international practice to present the costs of road crashes as a percentage of GDP (Wijnen & Stipdonk, 2016; WHO, 2015; Elvik, 2000). However, the costs included intangible costs (human costs) which are not part of a country's GDP. Moreover, resources used for, for example, medical treatment and vehicle repair are regarded as costs in the welfare economic perspective. From the perspective of the GDP, however, medical treatment and vehicle repair contribute positively to

[14] The value transfer function was modelled for the GDP per capita and VSL expressed in 2005 international dollars. We follow the calculation procedure described by Milligan et al. (2014) by first translating the GDP per capita in national currency 2012 into 2005 international dollars. Next, the VSL in international dollars 2005 resulting from the value transfer function has been transferred back to national currency 2012. The purchasing power parity in 2012 and GDP deflator indices for the US dollar in 2005 and 2012 from the World Bank (2017) have been used for these conversions.

GDP. Consequently, estimating the impact of road crashes on the GDP requires a different type of analysis (World Bank, 2017b).

A comprehensive estimation of road crash costs is quite demanding in terms of data requirements. Our analysis shows that a large variety of data is needed, including road safety, economic, demographic, medical, emergency service and insurance data. Although several types of data were not available in Kazakhstan, we were still able to make an estimate of all relevant cost elements. Data gaps were bridged by conducting a survey and using data from other countries (value transfer). Value transfer is commonly applied in road crash cost studies, although inevitably it brings along a certain level of uncertainty. Nevertheless, we consider value transfer as a preferable option when compared to fully omitting certain cost elements as this would result in underestimating the costs. This, in turn, would have bearing on the safety benefits if the results were to be applied in cost-benefit analysis. Still, it cannot be denied that data limitations pose a serious challenge for future road crash studies in other countries, particularly in low- and middle-income countries. This applies to the data concerning the number of road casualties and crashes, and a proper system for accident reporting and addressing underreporting is essential. Moreover, collecting data through surveys is recommended for future road crash cost studies in other countries. This will improve the international knowledge base on road crash costs in low- and middle-income countries, and allow more countries to use value transfer to supplement their national data.

The large socio-economic costs of road crashes in Kazakhstan indicate that significant benefits are to be expected from investments in road safety. Consequently, policy makers can use the results of this study for justifying (additional) government spending on prevention of road crashes and for setting priorities in the allocation of government budgets. Furthermore, this study provides essential input for cost-benefit analysis, which can help policy makers to spend (road safety) budgets efficiently. In a cost-benefit analysis the socio-economic crash cost savings are weighted against the cost of implementing road safety measures, in order to identify the most cost-beneficial investment options. Reviews of cost-benefit analyses of road safety measures show that the benefits of road safety investments are often (much) higher than the costs, due to high socio-economic costs of road crashes (Daniels et al., 2019). Moreover, there is evidence that the number of casualties can decrease dramatically if the most cost-beneficial measures are implemented (Elvik, 2003). This study indicates that similar results are likely to be expected in Kazakhstan, although further research on road safety programs and their costs and benefits would be needed to confirm that.

4.8. Conclusions

The socio-economic costs of road crashes in Kazakhstan are estimated at $6.8 billion, which corresponds to 3.3% of GDP. This estimate can be regarded as a lower limit of the costs, particularly given the fact that conservative estimates of the number of casualties and crashes have been used. This indicates that road crashes result in a huge and considerable socio-economic burden for the country of Kazakhstan. Given the relatively poor road safety performance in Kazakhstan when compared to other middle-income countries, combined with a relatively good economic performance, this was to be expected. The study shows that a comprehensive road crash cost assessment requires a wide variety of data from different types of data sources, which are often not readily available. Most data gaps can be bridged, however, by conducting a household survey or by using data from other countries. In the future, it would be recommended that similar studies in other middle-income countries be conducted, as this will help policy makers and other stakeholders to set policy priorities and to increase the awareness of road safety as a socio-economic problem, particularly in middle-income countries.

Acknowledgement

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Appendix 1: Questionnaire Road crash costs Kazakhstan

Settlement:	Urban – 1. Rural – 2.	
Region:	Code:	Rayon:
Location: House – 1. Apartment – 2. Shopping center – 3 . Garage – 4.		

QUESTIONNAIRE ON ROAD SAFETY

Introduction

Each year about 3,000 people in Kazakhstan die in a road crash, and there are many more injuries and accidents with property damage. This survey is part of a national study into the costs of road crashes, carried out on behalf of the Government of Kazakhstan. The results will be used to calculate the costs of road crashes in Kazakhstan, and to improve road safety policy making. It is a survey among the population of Kazakhstan, and it is conducted to get information about your perception of road safety risks, what it is worth for you to improve road safety, and about damage to cars because of an accident. You have been selected to participate in this survey, and so I would like to ask you a couple of questions. Your answers will be treated strictly anonymously and confidentially. The questionnaire takes at most about 20 minutes.
-> Would you like to participate?

Part 1: Road accident risks

Every day about 8 persons die in a road accident in Kazakhstan, which is equal to about 3,000 people per year. This is about 20 fatalities per year per 100,000 Kazakh citizens. To give an illustration of this risk, I show you a paper with 100,000 grid boxes, of which 20 boxes are shaded. [Interviewer: show 1st paper with grid boxes] Now I show you the backside of the paper. Suppose that you put a needle in the paper. The chance of touching a shaded box if you put a needle in the paper is about the same as the chance of dying in a road accident in a year. This is a chance of 20 out of 100,000.

Now I show you a similar paper, but on this paper 10 out of 100,000 grid boxes are shaded. [Interviewer: show 2nd paper with grid boxes and shows then the back side] Again suppose that you put a needle in the paper.

Q1: Is the chance of touching a shaded box lower or higher compared to the first paper?

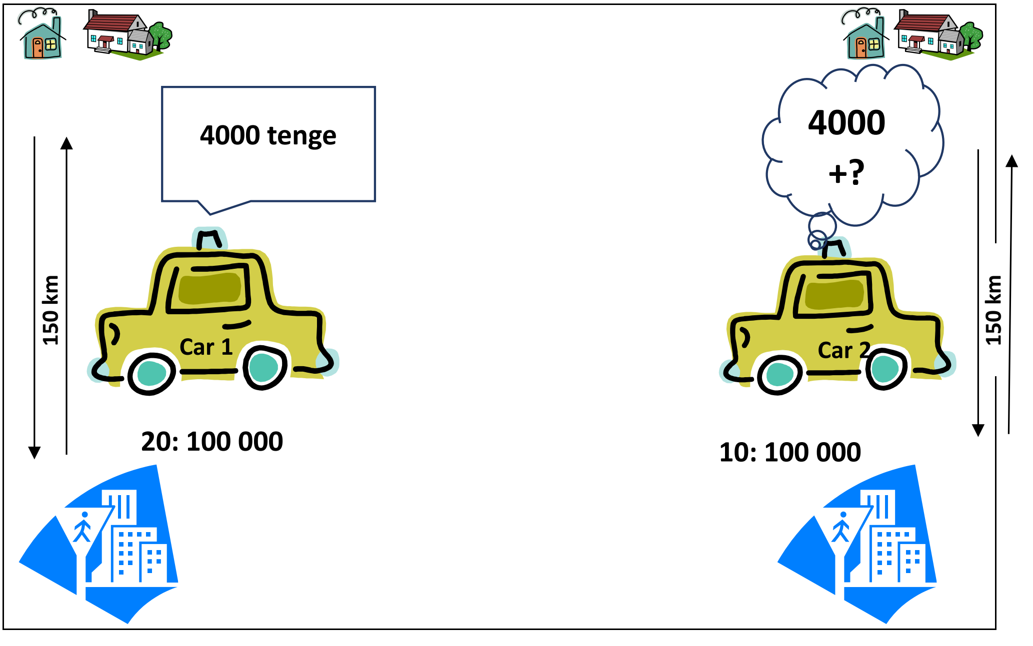
Lower □ Higher □

If higher -> skip to Q3

Q2: Touching a shaded box in the second paper, compared to the first paper, is:

Half as likely □ A quarter as likely □ Other □__________

Now I ask you to imagine that you travel once every month from your home town to a place at a distance of about 150 kilometres from here. For this trip you travel by car with a driver. The costs of a round trip (300 km) are about 4000KZT. You can choose between two cars with a driver. The driving behaviour, including their speed, of the two drivers is the same. The travel time is about 2 hours for a single trip. However, the safety of the two cars is different. If you travel with car 1 you have a yearly risk of being killed in an accident of 20:100,000. Car 2 has been tested as a safer car, because it has more safety features. With this car your yearly risk of being killed in an accident is 10:100,000. However, if you choose this car you will have to pay an additional charge. There are no other differences, for example regarding driving comfort, between the two cars.
[Interviewer: show paper with the summarizing picture] This picture summarizes this information.



The next two questions are about which charge you would be willing to pay for your better safety in car 2 compared to car 1.

Q3: What is the maximum charge that you would be willing to pay per round trip, that means every month, for your better safety in car 2 compared to car 1?

To help you answering this question, I show you a card with several possible amounts. [Interviewer: show payment card 1] Which amount is closest to the maximum amount you would be willing to pay for car 2?

…………KZT

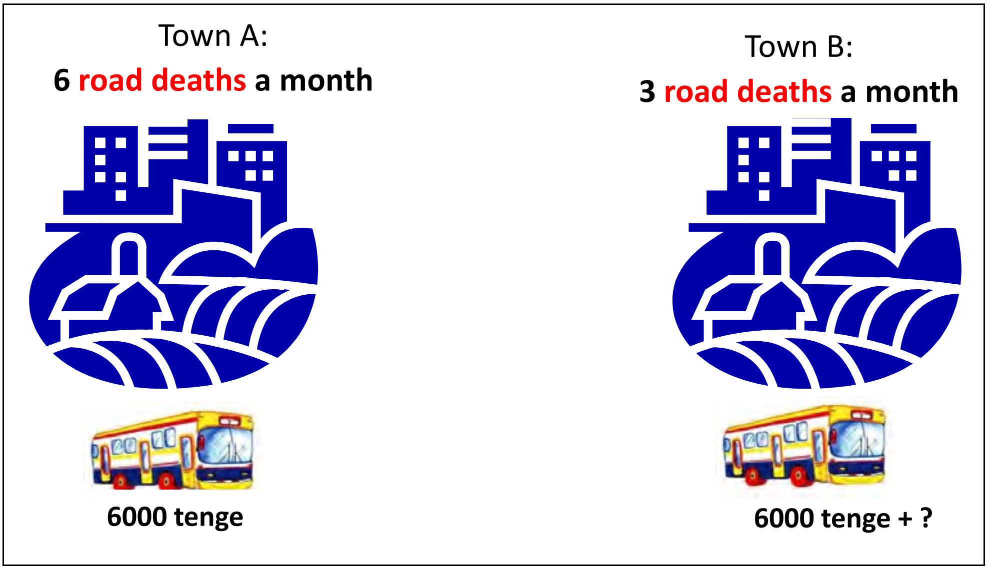
PAYMENT CARD 1

What is the maximum additional amount you would be willing to spend monthly for your better safety in car 2?
(amounts in KZT)

less than 100	**100**	**200**	**300**	**400**
500	**600**	**700**	**800**	**900**
1000	**1100**	**1200**	**1300**	**1400**
1500	**1750**	**2000**	**2500**	**more than 2500**

Or any other amount not mentioned above

[Interviewer: show paper with the summarizing picture B]. Now suppose that you move to a town because of your work (or to another if you already live in a town). There are two cities you can choose from. The two cities are identical, except the road safety level and the costs of travelling to and from your work. Both cities have 300,000 inhabitants. You travel by bus to and from your work and the travel time from your home to your work is the same in both cities. In town 1 the costs of travelling to and from your work are 6,000KZT per month. In town 1 there are every month 6 deaths because of road crashes, including people travelling to and from work by bus. In town 2 there are every month 3 deaths because of road crashes.



Q4: What is the maximum *extra* amount that you would be willing to pay per month for travelling to/from your work in the safer town B, compared to town A?

To help you answering this question, I show you a card with several possible amounts. [Interviewer: show payment card 2] Which amount is closest to the maximum amount you would be willing to pay in town 2?

…………KZT

PAYMENT CARD 2

What is the maximum *extra* amount you would be willing to spend monthly on travel costs in town 2, compared to town 1?

(amounts in KZT)

less than 100	**100**	**200**	**300**	**400**
500	**600**	**700**	**800**	**900**
1000	**1100**	**1200**	**1300**	**1400**
1500	**1600**	**1700**	**1800**	**1900**
2000	**2250**	**2500**	**3000**	**more than 3000**

Or any other amount not mentioned above

Part 2: Injuries and car damage resulting from an accident

This part of the questionnaire is about accidents and injuries and car damage resulting from accidents. By 'accident' we mean any incident which involved injury to another person or yourself, damage to property, damage to another vehicle, or damage to your car.
The accident should have occurred on public roads (not on private property) and should have involved a motorized vehicle.

Q5. Have you, or one of the members of your household, been involved in such an accident in the last three years?

Yes □ No □

If no -> skip to Q13

Q6. How many such accidents were you involved in yourself (not household members)?

………….. accidents

Q7. How many such accidents were your household members involved in?

………….. accidents

Q8. What was your mode of transport when you, or your household member, had the accident(s)

	Most recent accident	Next most recent
Bicycle	□	□
Motorcycle	□	□
Car	□	□
Van	□	□
Truck, bus (driver)	□	□
Bus passenger	□	□
Pedestrian	□	□
Other (please specify)	…..	…..

Q9. Did you, or your household members, have any injuries? And if yes, what was the severity of the injury?

	Most recent accident	Next most recent
None	□	□
Slight, no hospital treatment	□	□

Slight, hospital treatment (but no overnight stay in hospital)	□	□
Severe (overnight stay in hospital)	□	□
Fatal injury	□	□

Q10. Were there any injuries to others involved in the accident?

	Most recent accident	Next most recent
None	□	□
Slight (no hospital treatment)	□	□
Slight, hospital treatment (but no overnight stay in hospital)	□	□
Severe (overnight stay in hospital)	□	□
Fatal injury	□	□

Q11. Did the police come to the place of the accident?

	Most recent accident	Next most recent
Yes	□	□
No	□	□

If yes for both accidents -> skip to Q13

Q12 If the police did not come, did you or somebody else subsequently report the accident to the police?

	Most recent accident	Next most recent
Yes	□	□
No	□	□

The remainder of this part of the questionnaire is about damage to your car due to an accident. This part of the questionnaire only applies to you if you possess a car yourself or if you have a car available for yourself as a driver.

Q13: Do you have a car?

Yes □ No □

If no -> skip to Part 3

Q14: Have you, as a car driver, been involved in an accident in the last three years?

Yes □ No □

If no -> skip to Part 3

The next questions are only about the latest accident you were involved in.

Q15: How much damage was done to your car in that accident?

No damage □
Slight damage (dents and scratches) □
Serious damage □
Total loss (write off) □

Q16: How much, approximately, were the costs of repairing your car or replacing it?

.... KZT

Q17. What kind of insurance did you have?

None □ Liability □ Casco □

If none or liability -> skip to Q22

Q18: Did you submit a claim for this damage to your car at your insurance company?

Yes □ No □

If no -> skip to Q22

Q19: Was your claim rewarded?

Yes □ No □

If no -> skip to Q22

Q20: How much did the insurance company pay you?

…………….. KZT

Q21: Did this amount include a payment for any injury?

Yes □ No □

Q22. How many other vehicles were involved in the accident?

None □
1 □
2 □
3 □
4 □
More than 4 □

If none -> skip to Q27

Q23. Were you liable for the damage to other vehicles?

Yes □ No □

Q24: Has a claim for this damage been submitted at your insurance company?

Yes □ No □

Q25 Did you pay the owner of the other vehicle yourself to compensate his/her damage?

Yes □ No □

If no -> skip to Q27

Q26: How much did you pay the owner of the other vehicle?

…………….. KZT

Q27: How many days was your car not at your disposal due to the crash?

……… days

Q28: Did you rent a car when your car was unavailable?

Yes ☐ No ☐

If no -> skip to Part 3

Q29: How many days did you rent a car?

……… days

Part 3: general questions

Finally, we want to ask a few general questions about you.

Q30: Which mode of transport do you use most frequently?

Bicycle ☐
Motorcycle ☐
Car ☐
Van ☐
Truck/bus (driver) ☐
Bus passenger ☐
Pedestrian ☐
Other (please specify)…

Q31: What is your age?

…….years

Q32: Are you male or female?

Male ☐ Female ☐

Q33: What is your ethnicity?

Kazakh ☐
Russian ☐
Other (please specify)…….

Q34: What is your highest education?

Undersecondary ☐
Secondary ☐
Secondary professional ☐
Higher ☐

Q35: How many members does your household (family) have?

……… members

Q36: In what category is the monthly income of your household?

Less than 50,000 KZT	□
50,000 - 100,000 KZT	□
100,001 - 200,000 KZT	□
200,001 - 300,000 KZT	□
300,001 - 500,000 KZT	□
More than 500,000 KZT	□

Thank you very much for your cooperation!

Appendix 2: Data from other countries used in the cost calculations.

Country	Source	ratio number of serious injuries/fatalities	ratio number of slight injuries/serious injuries	ratio number of casualties/ number of crashes			number of fatalities treated in hospital	duration hospitalization fatalities (days)	duration absence from work (days)		ratio costs other emergency services/police costs
				fatal	*serious injury*	*slight injury*			*serious injuries*	*slight injuries*	
Australia	BITRE (2009)	13	11	1.1	n.a.	n.a.	21%	6.2	32-260	5	0.89
Austria	Sedlacek et al. (2012)	7	9	1.06	n.a.	n.a.	33%	5.3	133	13	0.71
Belgium	De Brabander & Vereeck (2007)	6	7	n.a.	n.a.	n.a.	n.a.	n.a.	38	2	
Germany	Baum et al. (2007)	14	5	1.08	1.15	1.35	n.a.	n.a.	47	9	n.a.
Netherlands	De Wit & Methorst (2012)	26	15	n.a.	n.a.	n.a.	n.a.	n.a.	71	n.a.	0.53
New Zealand	Ministry of Transport (2006, 2013)	12	9	1.07	1.18	1.29	n.a.	n.a.	12	3	n.a.
Switzerland	Sommer et al. (2007)	18	11	n.a.	n.a.	n.a.	n.a.	n.a.	36-637	12	n.a.
UK	DfT (2013)	49	8	n.a.	n.a.	n.a.	n.a.	4.6	64	10	n.a.
US	Blincoe et al. (2014)	15	12	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

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5. Economic valuation of preventing non-fatal road injuries: a literature review

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Submitted

Abstract

This paper reviews the literature on monetary valuation of non-fatal road casualties, which have gained more attention in road safety policy making in recent years. A classification of willingness to pay methods is presented and the appropriateness of the methods is assessed using five criteria. Stated choice (SC) is the preferred method, particularly because of the theoretical basis and reliability. However, SC is not well suited to include different injury types and severities, as opposed to the Quality Adjusted Life Years (QALYs) method. Combining SC and QALYs can be a promising direction for future research. Although our review shows that the range of values of a prevented serious injury is very wide, 1% to 48% of the value of a statistical life, it indicates that preventing serious road injuries is at least as relevant as preventing fatalities from a socio-economic point of view. It is recommended to enlarge the empirical basis of the monetary valuation of non-fatal road injuries by conducting more valuation studies, since the number of valuation studies is very small. Values that international guidelines recommend for practical applications are based on dated literature and need to be updated.

Keywords: non-fatal injury, road safety, willingness to pay, costs, QALY, cost-benefit analysis

5.1. Introduction

Economic assessment of road safety projects and transport projects with an impact on road safety, particularly cost-benefit analysis, require economic valuations of preventing road casualties (see for example, Boardman et al., 2011). In addition, monetary valuations are needed for assessments of the socio-economic costs of road crashes, including valuations of road casualties of different severities, such as fatalities, serious injuries and slight injuries. Estimates of the costs of road crashes are made in many countries (WHO, 2015; Wijnen et al., 2019) and the results such cost assessments are an essential input for cost-benefit analysis of transport projects (Wijnen and Stipdonk, 2016).

The monetary valuation of preventing road casualties has been reviewed extensively in the literature (De Blaeij et al., 2003; Dionne & Lanoie, 2004; Lindhjem et al., 2011; Bahamonde-Birke et al., 2015). However, these reviews concentrate on fatalities and the 'value of a statistical life' (VSL) as a concept for expressing prevented fatalities in monetary terms. A review of monetary valuations of preventing non-fatal road injuries is missing in the literature, which is striking for two reasons. Firstly, non-fatal injuries account for a large proportion of the socio-economic costs of road crashes. The annual number of road injuries is estimated at 20 to 50 million globally (WHO, 2022) and a review of studies on the socio-economic costs of road crashes in 17 countries shows that non-fatal injuries account for about 50% of the total costs, both in high-income and low- and middle-income countries (Wijnen and Stipdonk, 2016). In a review of the official road crash cost estimates in 31 European countries, costs of serious and slight injuries were found to represent 7.4–55% and 14–77% respectively of the total road crash costs, while fatalities account for 1.9–34% (Wijnen et al., 2019). Consequently, a major part cost savings resulting from road safety interventions, and thus the road safety benefits in a cost-benefit analysis, is likely to be related to the prevention of non-fatal injuries. Secondly, the number of serious road injuries tends to decrease more slowly than the number of fatalities (ITF, 2019). Consequently, serious road injuries have gained more attention in road safety policy making in recent years. This is reflected, for example, by the 'Decade of action for road safety' that was proclaimed by the United Nations and included the ambition to prevent 50 million serious injuries in the period 2011-2020 (WHO, 2011). Moreover, road safety policies in several European countries include a target for reducing serious injuries (Van Wee, Hagenzieker and Wijnen, 2014) and in 2017 the transport ministers of the European Union member states agreed to add a quantitative target for reducing road injuries (50% reduction between 2020 and 2030) to the fatality target (MaltaEU, 2017).

Despite this attention for preventing non-fatal road injuries, the literatures provides hardly any guidance on how to determine the monetary valuation of preventing these injuries. Also, a systematic review of the literature on this topic has not been made until now. Consequently, systematic information on the economic benefits of preventing road injuries is missing or insufficient. This is an impediment for assessing the socio-economic costs of road crashes and cost-benefit analysis, and thus for (road safety) policy making. The aim of this article is to critically review methods for monetary valuation of preventing non-fatal road injuries or reducing injury severity and the valuations that have been found in the literature, as well as to give recommendations for monetary valuation of preventing road injuries.

This article concentrates on willingness to pay (WTP) methods, which are generally recommended for monetary valuation of (road) injuries (Jones-Lee, 1990; Boardman et al., 2011; Robinson & Hammitt, 2013; Freeman et al., 2014; Wijnen et al., 2019). This method is aimed at determining the amount of money people are prepared to pay for a reduction of the probability of dying or getting injured in a road crash. The concept of WTP is consistent with economic welfare theory (see e.g. Johansson, 1991) and with the theory of social cost-benefit analysis, which is rooted in welfare economics (see e.g. Boardman et al., 2014). The WTP-approach is primarily aimed at estimating the human costs of road injuries, which are the intangible cost of lost quality of life and life years. A review of non-fatal road injury costs in European countries showed that human costs account for a large proportion of the total non-fatal injury costs, 51% to 91% in countries which use a willingness to pay approach (Schoeters et al., 2017). Other cost related to non-fatal injuries are medical costs and production loss, which are usually much smaller than the human costs. Recommended methods for estimating these other costs are the restitution costs method and human capital method respectively (Schoeters et al., 2020; Wijnen et al., 2019; Alfaro et al., 1994). Since these methods rely on market prices, they are much more straightforward and undebated than the WTP approach and they are generally applied in road crash cost studies (Wijnen & Stipdonk, 2016; Wijnen et al., 2019). For these reasons, these methods are not further discussed here.

This article is structured as follows. Section 5.2 presents a classification of WTP methods for valuation of non-fatal road injuries and discusses each method as well as the outcomes of studies in which they have been applied. Based on the strengths and weaknesses of the methods as discussed in the literature, the appropriateness of the methods for monetary valuation of preventing non-fatal road injuries is assessed (Section 5.3). The implications of the findings of this literature review for practical applications, such as cost-benefit analysis and assessing the socio-economic costs of road crashes, are discussed in Section 5.4, followed by conclusions (Section 5.5).

5.2. Willingness to pay methods for valuation of non-fatal road injuries

Three WTP approaches for the economic valuation of road injuries can be distinguished:

- Direct WTP approaches: the WTP for reducing the risk of getting injured in a road crash is obtained in a direct way using stated or revealed preference methods.
- Indirect WTP approaches: the WTP for reducing non-fatal risks is determined relative to the WTP for a fatal risk reduction and the value of a non-fatal injury is calculated as a proportion of the VSL.
- QALY-approach: the monetary valuation of a road injury is calculated on the basis of the loss of quality of life, as measured by Quality Adjusted Life Years (QALYs) and the monetary valuation of a QALY.

Figure 5.1 presents an overview of these three approaches and methods that belong to each approach. The following sub-sections discuss these three approaches and studies in which they have been applied in more detail.

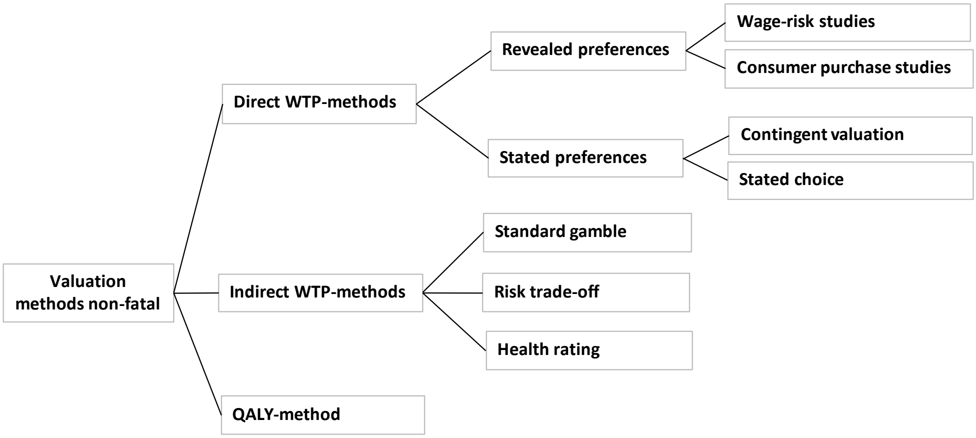

Figure 5.1: Classification of WTP methods for valuation of non-fatal road injuries

5.2.1. Direct WTP approaches

In general, there are two direct approaches to determine the WTP for fatal or non-fatal crash risk reductions: stated preference (SP) methods and revealed preference (RP) methods (De Blaeij et al., 2003; Robinson & Hammitt, 2013; Milligan et al., 2014). In the SP approach people are asked how much they are willing to pay for (hypothetical) crash rate reductions, using questionnaires. Two types of SP methods are distinguished: contingent valuation and stated choice (Bahamonde-Birke et al., 2015). In the contingent valuation method people are asked, more or less directly, which amount of money they are willing to pay for a crash risk reduction, while in stated choice respondents are asked to make a choice between several situations that have different aspects (attributes). In the case of road safety, the attributes should include a risk level (fatal or non-fatal) and a monetary attribute such as travel costs.

RP methods derive the WTP from people's actual behaviour and choices concerning safety. There are two main types of RP methods that can be applied to road safety: wage-risk studies and consumer purchase studies (Elvik, 2016). In wage-risk studies, also known as 'hedonic wage' or 'hedonic prices' studies, the wage difference between workers who are exposed to different levels of mortality or health risks are examined (Viscusi, 1993). In consumer purchase studies, the valuation of risk reductions is derived from the price people pay for products that reduce risks, such as airbags or bicycle helmets.

RP methods have the advantage that the valuations are derived from people's actual behaviour, which is in general more accurate and reliable than people's statements about what they would do in certain (hypothetical) situations. However, RP methods are prone to 'selection bias', because the risk attitude of people with high-risk jobs is likely to be different than the average risk attitude of the general population (Bahamonde-Birke et al., 2015). Other disadvantages of RP methods are related to limited data availability and to the fact that the choice for safety products is often not made separately and explicitly (De Blaeij, 2003). Stated preference methods offer much flexibility and a wide applicability, related to the fact the questionnaires are used and the independence of data on actual behaviour. In addition, SP methods are better suited to cope with the fact that people have difficulties understanding small risks and, even if they do understand, to make choices concerning these small risks. SP methods offer the opportunity to test the respondent's risk understanding and to explain very small risks, for example using visual tools which results in more reliable estimates (Lindhjem et al., 2010). However, the results of stated preference studies are influenced by the design of the questionnaire and they are prone to several types of bias related to, for example, the information that is given to the respondent (e.g. on the safety situation) and the way people are supposed to pay for more safety ('payment vehicle'), see De Blaeij (2003) for an overview. Moreover, the results are influenced by the size of the risk change, the context (road safety, environmental risk, occupational risk) and the specific type of SP method that is used (Miller, 2000; De Blaeij et al, 2003; Lindhjem et al., 2010). Stated choice is mostly regarded as superior to other SP methods, due to the indirect way of eliciting the WTP (De Blaeij, 2003; Rizzi & Ortúzar, 2006; Bahamonde-Birke, 2015). However, stated choice is sensitive to lexicographic answers (respondents always chose the alternative with the best score on a particular attribute, e.g. the safest alternative) and inconsistent choices (respondents are asked to make a choice a number of times for different combinations of attributes but do not choose consistently). In the analysis of the stated choice data, it is important to assess the impact of these problems on the results.

Although both SP and RP are valid methods, reviews show that SP methods are much more commonly used to derive the VSL for road safety, particularly in Europe (De Blaeij et al., 2003; Lindhjem, 2010). This is likely to be explained by the greater flexibility of SP methods and the fact that SP applications do not require information on actual (purchasing) behaviour.

Direct WTP have been applied extensively to fatal road crash risks (De Blaeij, 2004; Lindhjem, 2011), but the number studies which include WTP for non-fatal road crash risks is limited. Table 5.1 gives an overview of direct WTP studies for non-fatal road injuries. The overview is based on a literature search using Scopus. The search string used was: (willingness to pay) AND (road OR traffic OR transport) AND injury. This resulted in 61 publications, 11 of which included the estimation of the value of a prevented road injury using a WTP method. We only included articles published in peer-reviewed journals as a quality criterion. An alternative search string using the term 'economic valuation' instead of 'willingness to pay' did not result in any additional publications. In addition, 'backward snowballing' (Van Wee & Banister, 2016) was applied, which resulted in two additional publications. In two studies (O'Reilly et al., 1994; Persson et al., 2001) different methods were used resulting in different valuations. All of the 13 studies included a valuation of preventing a serious injury, while five studies also included the valuation of a slight injury. Different definitions of serious and slight injuries were used in these studies. Two studies (Hensher et al., 2011; Niroomand & Jenkins, 2017) were replications of previous studies of the same authors with a different target group. In these studies the valuation of pedestrian injuries is determined, while the original studies (Hensher et al. 2009; Niroomand & Jenkins, 2016) were targeted on car drivers and car passengers.

The first study on the monetary valuation of non-fatal road injuries was conducted in the UK (O'Reilly et al., 1994; Jones-Lee et al., 1995). In this study the contingent valuation (CV) method was applied, in addition to standard gamble and health rating (discussed below). It was found that the sensitivity of the WTP amounts to the size of risk changes and injury severity was very limited. Also, the resulting value of preventing a serious injury was much higher than the value that was obtained from the standard gamble method. The researchers concluded that the CV values were seriously biased and that this method is not appropriate for monetary

Table 5.1: Overview of WTP-studies on non-fatal road injuries.

Study	Country	Method*	Value serious injury (% fatality)	Value slight injury (% fatality)	Definition serious injury	Definition slight injury
Direct WTP						
O'Reilly et al., 1994	UK	CV	32.8-37.5	-	Hospitalized, or having any of the following injuries: fractures, concussion, internal injuries, crushings, severe lacerations, and severe general shock requiring medical treatment.	-
		HR	3.6-37.1	-		
Persson, 2001	Sweden	CV	13.3-26.4	0.5-1.2	Disabling	Not specified
Hojman et al., 2005	Chile	SC	47.0	-	Not reported (several examples of severe road traumas were given in the questionnaire)	-
Hensher et al., 2009	Australia	SC	0.9-4.9	0.3	Hospitalized long duration with permanent disability - hospitalized with full recovery	Medical treatment without hospitalization
Hensher et al., 2011	Australia	SC	2.7-7.5	0.9	Hospitalized long duration with permanent disability - hospitalized with full recovery	Medical treatment without hospitalization
Chaturabong et al., 2011	Thailand	CV	47.2-48.5	-	Not specified	-
Niroomand & Jenkins, 2016	Cyprus	SC	2.4**		Not specified	-
Niroomand & Jenkins, 2017	Cyprus	SC	2.9**		Not specified	-
Gonzales et al., 2018	Spain	SC	17.0	-	Hospitalized more than 24 hours	-
Puttawong & Chaturabong, 2020	Thailand	CV	3.4	-	Not specified	-
Schoeters et al., 2022	Belgium, France, Germany, Netherlands	SC	15.3	-	Injury severity MAIS3+ (Maximum Abbreviated Injury Scale)	-

Table 5.1 (continued)

Study	**Country**	**Method***	**Value serious injury (% fatality)**	**Value slight injury (% fatality)**	**Definition serious injury**	**Definition slight injury**
Indirect WTP						
O'Reilly et al., 1994	UK	SG	9.5	-	Hospitalized, or having any of the following injuries: fractures, concussion, internal injuries, crushings, severe lacerations, and severe general shock requiring medical treatment.	-
Persson, 2001	Sweden	SG	40.4	32.1	Disabling	Not specified
Persson, 2001	Sweden	RTO	38.2	2.3	Disabling	Not specified
Koyama & Takeuchi, 2004	Japan	SG	22.4	1.5-2.4	Having a serious injury or serious health problems as a result of a road crash (not specified, examples are given including eye injury, leg/arm movement limitations and inability to work due to internal organ or nerve injury)	Some pain/discomfort for several weeks, return to normal health after 1-3 months
Direct and indirect WTP						
Olofsson et al., 2019	Sweden	CV+SG (chained)	1.3-67.0	1.3	Moderate to severe health problems during 6 months, 12 months or permanently and permanent slight health problems, slight/moderate/severe defined using EQ-5D	Slight health problems during 6 months, slight defined using EQ-5D

* CV: Contingent valuation, HR: Health Rating, SC: Standard Choice, SG: Standard Gamble, RTO: Risk Trade-Off
** Severity not specified

valuation of road injuries. Although Persson et al. (2001), who applied the CV method for the valuation of road injuries in Sweden, were more positive about the CV method, CV has been used only in two studies in Thailand since then. Other WTP-studies mostly used the choice (SC) method, which was introduced for determining the VSL in the context of road safety early this century (Rizzi & Ortúzar, 2003).

Table 5.1 shows that the value of preventing a serious injury, as a percentage of the VSL as estimated in the same study, vary considerably. There is no clear relation between the method and the values found. Values found in CV studies range from 3.4% to 48.5% and values found in SC studies from 1.5 to 47.0%. In the chained approach, Olofsson et al. (2019) found values ranging from 1.3% to 67.0% of the VSL, depending on injury severity. Different definitions of a serious are used in the studies, but this does not explain the variation. For example, Hensher et al. (2009) estimated the value of preventing an injury resulting in permanent disability at 4.9% of the VSL, while Gonzales et al. (2018) found a value of 17% for all injuries that required hospitalization for at least 24 hours. The variation is likely to be explained by differences in the survey design and the input parameters which are used in the questionnaire and in the calculations of the value of a prevented injury. For example, the results are known to be dependent on the assumed baseline risk, the size of the risk reduction and the (assumed) traffic volume.

The value of preventing a slight injury shows less variation than the values of serious injuries: 0.5% to 1.2% of the VSL. It is remarkable that most SC studies, which has become the most popular method in recent years, have not included a valuation of slight injuries. Possibly the researchers want to avoid making the survey design too complex and presenting too much information and choices to the respondents. Moreover, they may take into account that serious injuries are more relevant from a road safety policy perspective.

Although CV is often assumed to overestimate the value of risk reductions, this is not confirmed by our overview. For example, Persson et al. (2001) found a range of 13.3-26.4% of the VSL for disabling injuries using CV, which is in the same order of magnitude of values found in the SC studies by Veisten et al. (2013) and Gonzales et al. (2018). However, the number of studies is very limited, which makes it hard to draw any conclusions about differences between results of CV and SC studies. Our literature search shows that revealed preference methods have not been applied to non-fatal road injuries. However, they have been applied outside the field of road safety, in particular in some wage-risk studies (Viscusi and Aldy, 2003).

5.2.2. Indirect WTP methods

There are several approaches to determine the value of reducing non-fatal risks relative to fatal risks, in particular the standard gamble method, trade-off methods and the health rating method (Boardman et al., 2011; Brent, 2014; Elvik, 2016). These approaches allow calculating the monetary valuation of preventing injuries in an indirect way, as a proportion of the VSL.

The standard gamble method was introduced by Neumann and Morgenstern (1944) and is rooted in their utility theory. In this method people are asked to make choices between two alternatives. The first alternative has a certain health outcome, e.g. specified in terms of number of remaining life years and the quality of these life years. In the second alternative there are two possible health outcomes, typically either returning to normal health or death. Then the probabilities of those two outcomes which make the respondent indifferent between alternative 1 (a certain health outcome) and alternative 2 (a chance of returning to normal health and a chance of dying) are determined. The valuation of the health outcome in alternative 1 relative to death or to perfect health is obtained from these probabilities. The standard gamble method was introduced in a road safety context in the UK (O'Reilly et al., 1994) and subsequently applied in Sweden (Persson et al., 2001) and Japan (Koyama & Takeuchi, 2004). The values of a serious injury range from 9.5% to 40.4% of the VSL and the value of a slight injury from 1.5% to 2.4% of the VSL (Table 5.1) if the outlier (32.1%) found by Persson et al. (2001) is excluded. The authors of the latter study admit that their value of a slight injury in unrealistically high, which they attribute to several anomalies in the survey design.

In the risk trade-off method (also known as risk-risk method) respondents are asked to trade-off different types of risks, for example an increase in the risk of getting injured versus a decrease in fatal risk. For example, Persson et al. (2001) asked respondents to choose between two living areas with different risks of getting killed, getting slightly injured and getting seriously injured in a road crash, to obtain the valuation of preventing injuries relative to the value of preventing a fatality. Other trade-off methods are the time trade-off method (Torrance et al. (1972) and the person-trade-off method (Nord, 1992). In the first method, respondents are asked to make trade-offs between loss of quality of life and loss of life years, typically a reduction of remaining life years versus a longer life with a lower quality of the remaining life years. In the person-trade-off method, two different health improvements (slight and strong) are presented and respondents are asked to state the number of persons with the slight improvement that would equalize a given (lower) number of persons with the strong improvement. In this paper, we only include risk-trade off since this method is particularly aimed at monetary valuation of road crash risks.

In some studies, standard gamble is combined with contingent valuation, which is known as the 'chained approach' (Carthy et al., 1998). In this approach, respondents are asked to state their WTP for full recovery from a injury using contingent valuation and in a next steps respondents made trade-offs between reducing the risk of this non-fatal injury and fatal risks in a standard gamble survey design. The aim of the study by Carthy et al. (1999) was to estimate the VSL and they used the WTP for a slight injury as a first step to estimate the VSL. The underlying idea was that respondent were better able to state their WTP for preventing a slight injury than for reducing fatal risk, as most people are familiar with slight injuries. Olofsson et al. (2019) applied the chained approach to determine the monetary valuation of road injuries of different severities (slight to fatal) and the valuation of a QALY.

Standard gamble is regarded as theoretically superior to other indirect WTP-methods because of its consistency with economic utility theory, although some assumptions made in the Neumann and Morgenstern theory are violated in practice (Brent, 2014). Trade-offs methods are also rooted in economic theory but suffer from similar limitations. For example, it is assumed that the proportion of lifetime people give up for a health improvement is constant, regardless of the remaining number of life years. Presumably this assumption is not met in practice, because people can adapt to a worse health state (Elvik, 2016). Consequently, they might be willing to give up less years if their expected number of remaining life years is larger than under the assumption of constant proportional trade-off of longevity for health. The health rating method is not directly related to economic utility theory and it is questionable whether the ratings that people state represent utilities. However, its practicability is a main advantage and for that reason this method has is commonly applied in the field of health care (Whitehead & Ali, 2010).

5.2.3. QALY method

A Quality Adjusted Life Year (QALY) represents the quality of life gains that result from injury prevention. In cost-utility analysis, health or injury prevention treatments are ranked according to the cost of the treatment per QALY gained. Although cost-utility analysis is mainly applied to health care interventions (for example see Brent, 2014), there are also applications to road safety interventions (Miller & Levy, 2000; Banstola & Mytton, 2016). QALYs can also be used for monetary valuation of (road) injury prevention, which requires availability of a monetary value of a QALY (Robinson & Hammitt, 2013; Brent, 2014). For example, assessments of the socio-economic costs in the United States include estimates of human costs of injuries based on QALYs (Blincoe et al., 2014).

A QALY comprises both mortality and morbidity by including two elements: a reduction of the number of years of life lost (YLL) and a reduction of the years lived with disability (YLD). With respect to non-fatal road injuries, only the morbidity part of a QALY (YLD gains) is relevant. The YLD combines the duration of loss of quality of life with the severity of the quality of life loss. Severity is expressed in disability weights, ranging from 0 (death) to 1 (perfect health). The disability weights are obtained by applying (one of) the indirect WTP methods discussed above (standard gamble, trade-off methods and health rating) to health states which are used in instruments for quantifying quality of life loss. Example of such an instrument are EuroQol (EQ-5D), Health Utility Index (HUI2, HUI3), Quality of Well-Being Scale and Short Form (SF-12, SF-36), see for example Nord (1999) and Van Beeck et al. (2007). A measurement of quality of life is obtained by combining the health state as measured by the instrument and the disability weight for the particular health state. In particular the EQ-5D instrument method has been found to be suitable for road safety applications (Elvik, 1995). It has integrated in a standard method for determining the YLD related to injuries (Haagsma et al., 2012) which has been successfully applied to road injuries (Polinder et al., 2015; Weijermars et al., 2018).

To translate QALYs into monetary units, estimates of the willingness to pay for a QALY are needed. In general there are two approaches to obtain the WTP for a QALY (Ryen & Svensson, 2014). Firstly, the WTP can be derived directly from a stated preference study. This means people are asked about the amount of money they are willing to pay for a specific health improvement. In contingent valuation studies respondents are typically asked to imagine that they face a certain health state (e.g. resulting from an injury) and to state their WTP for moving to a better health state (e.g. after medical treatment). Such studies include a method to establish disability weights (as discussed above), enabling the researcher to link the WTP to a health improvement in terms of QALYs (see for example Gyrd-Hansen, 2003). Secondly, a monetary value of a QALY can be derived from the value of a statistical life (VSL). The VSL represents the value of all remaining life years at a specific age, and thus the VSL can be translated into a value per life year (which is equal to a value per QALY or YLD) on the basis of (average) age, life expectancy and a discount rate. See for example Hirth et al. (2000), who translated a large number of VSL estimates into values per QALY.

Reviews of WTP-studies show large variation in the monetary value of QALY. In a review of 14 stated preference studies, Nimdet et et al. (2015) found that the ratio of the WTP per QALY to GDP per capita ranged from 0.05 to 5.40. The values were found to depend, among others, on the type of health scenario: an improvement of quality of life resulted in lower values (ratio QALY-value to GDP/cap is 0.59) than scenarios on extending or saving lives (2.03). Also the perspective of the study affected the results: higher values (2.16) were found in studies using a societal perspective than in studies using the individual perspective (0.63). The individual perspective means that the valuation concerns the respondent's own health whereas the societal perspective concentrates on the health of a certain population. Similar results were found by Ryen & Svensson (2014), who reviewed 24 studies on the value of a QALY. They included 21 stated preference studies and three studies which used VSLs to derive QALY-values. The studies using VSLs resulted in much higher values: the mean value per QALY was 242,371 Euro and the median 109,858 Euro versus 26,189 Euro and 19,196 Euro respectively for the stated preference studies. Ye et al. (2021) reviewed 33 studies on the WTP for a QALY. They conclude that the value per QALY is higher if the QALYs refer to quality of life gains, as compared to extending length of life. However, this result, which contradicts with the results from the previous reviews, was not found if outliers (the 2.5% or 5.0% highest and lowest values) were removed from the sample.

Not all studies included in Ryen & Svensson (2014), Nimdet et al. (2015) and Ye et al. (2021) are relevant for monetary valuation of preventing non-fatal road injuries and application in cost-benefit analysis. Firstly, some studies are aimed at the WTP for extending life or saving life instead of improving quality of life. Secondly, studies aimed at specific diseases are not relevant, because road injury can have several kinds of health consequences. Thirdly, some studies adopt the societal perspective, which contrasts with economic welfare theory on which cost-benefit analysis is based (see for example Johansson 1991). According to this theory, welfare is based on individual preferences for goods and services (including someone's health). Fourthly, several studies use patients with a specific disease as respondents instead of the general public. For the valuation of (preventing) health losses that affect different population groups (as opposed to people with a specific disease or injury), the general public is mostly regarded as the most appropriate target group (Dolan, 1999; Boardman, 2011).

Table 5.2 shows the values per QALY found in the studies included in Ryen & Svensson (2014), Nimdet et al. (2015) and Ye et al. (2021) which relevant for monetary valuation of road injuries on the basis of the four criteria discussed above. The mean values are included, or the highest and lowest value if the mean was not reported. The values found in the first 10 studies are taken from Ryen & Svensson (2014) which were expressed in Euro 2010. They are converted into 2019 price level using consumer price indices (CPI) and adjusted for price level differences using purchasing power parities (PPP) as this was not done by Ryen & Svensson (2014). The other values are taken directly from the studies included in the review by Ye et al. (2021). These values are expressed in price level 2019 using CPI and converted from national currencies into Euro using PPP. CPI data from the World Bank (World Development Indicators, version 26-4-2021) and PPP data from the World bank and the Eurostat data browser (version 15-02-2021) were used.

The range of QALY values found in these studies is extremely wide: from 1,355 to 386,173 Euro. One of the explanations of the variation in values per QALY concerns insensitivity of the WTP to injury severity and duration (Olofsson, 2019). Also the size of the QALY gains influences the value per QALY: larger QALY gains tend to result in a lower valuation per QALY (Ryan & Svensson, 214). All studies used contingent valuation to elicit WTP, except Olofsson et al. (2019) who used a chained approach (contingent valuation and standard gamble). The methodologies used by Bobinac et al. (2014) and Soeteman et al. (2017) deviate from those used in the other studies, because they determined the valuation of reducing the risk of health losses instead of the valuation of certain health gains in the other studies. These methodological differences may explain the high values found in these three studies.

It is striking that almost all studies applied contingent valuation, while this method is known to be vulnerable for several types of bias (as discussed above). In principle other stated preference methods could be used as well. For example, in a stated choice approach respondents could be asked to make choices between several alternatives (e.g. alternative medical treatments) which are different in terms of the price and the health outcomes.

Table 5.2: Monetary values of a QALY found in WTP studies. Source studies 1-10: Ryen & Svensson (2014) .

Study		Country	Value (Euro, 2019 PPP)
1.	Gyrd-Hansen (2003)	Denmark	11,360
2.	Pinto-Prades et al. (2009)	Spain	38,628
3.	Bobinac et al. (2010)	Netherlands	17,336
4.	Zhao et al. (2010)	China	8,730
5.	Bobinac et al. (2012)	Netherlands	9,789
6.	Gyrd-Hansen & Kjær (2012)	Denmark	4,550
7.	Pennington (2013)	Denmark, France, Hungary, Netherlands, Norway, Poland Spain, Sweden, UK	14,020
8.	Robinson (2013)	Denmark, France, Hungary, Netherlands, Norway, Poland Spain, Sweden, UK	23,150
9.	Shiroiwa et al. (2013)	Japan	35,566
10.	Bobinac et al. (2014)	Netherlands	119,552
11.	Shafie et al. (2014)	Malaysia	15,182
12.	Ahlert et al. (2016)	Germany	12,177
13.	Soeteman et al. (2017)	Netherlands	216,960 - 386,173
14.	Song & Lee (2018)	South Korea	12,674 - 29,574
15.	Sund & Svensson (2018)	Sweden	14,427 - 31,401
16.	Lim et al. (2019)	Malaysia	6,244 - 13,878
17.	Olofsson et al. (2019)	Sweden	252,235
18.	Moradi et al. (2019)	Iran	1,355 - 4,812

5.3. Assessment and discussion of the methods

All three types of WTP-methods discussed in this article have their pros and cons with respect to suitability for monetary valuation of non-fatal road injuries. To judge the appropriateness of the three approaches, we assess the methods using five criteria which are assumed to be relevant for research on monetary valuation of preventing non-fatal road injuries and for applicability of the results of such research in social cost-benefit analysis:

- Theoretical basis and consistency with economic welfare theory, which ensures that the values are applicable in cost-benefit analysis.
- Reliability: to what extent is the method vulnerable to bias?
- Ability to handle injury diversity: road injuries are very diverse, which means that ideally a method should be able to determine valuations for a wide range of injury types and severities.
- Ethical issues: to which extent is the method vulnerable to ethical concerns, for example with respect to asking people's WTP for reducing risk, making trade-offs between fatal and non-fatal risks, or sensitiveness of the outcome to respondents' characteristics such as age?
- Practicality: to what extent is the method complex to apply? Does the method require, for example, complex questionnaires or specialized research skills?

5.3.1. Theoretical basis

The direct and indirect WTP-methods discussed in this paper, except the health rating method, are rooted in welfare economic theory, in the sense that they are aimed at measuring the individual WTP for reducing injury risk or for health gains. The same applies to the QALY approach, if the monetary value of a QALY is based on a sound WTP-method. Nevertheless, in particular standard gamble, risk trade-off and stated choice are regarded as theoretically superior methods due to their focus on trade-offs that individuals, which are based on the Von Neumann-Morgenstern utility theory (Neumann and Morgenstern, 1944) and random utility theory (Mc Fadden, 1974). However, an important limitation of standard gamble is that the fact that the situation after being injured is taken as the reference, instead of current situation of the respondent. The same applies to the risk trade-off method. This ex-post approach conflicts with the ex-ante approach of evaluating interventions in a cost-benefit analysis (Hojman et al., 2005; Bahamonde-Birke et al., 2015). Also, it contrasts with the practice of valuing fatal risks, which by definition can only be done ex-ante. This limits the suitability of the indirect WTP-methods for economic valuation of preventing road injuries from a theoretical point of view. As discussed by Hammitt (2002) and Elvik (2016), the QALY approach has some theoretical limitations related to assumptions on the utility functions underlying individual preferences. For example, preferences for extending life should not depend on health state and vice versa ('mutual utility independence'). This is related to the fact that QALYs are calculated as the product of health state and duration of the health state. It is unlikely that this requirement is met, as valuations for extending life are expected to be lower if someone has a worse health.

5.3.2. Reliability

Stated preference methods (CV, SC, SG and RTO) are known to be prone to several types of bias, mainly related to the questionnaire design, as discussed above. De Blaeij (2003) gives a detailed overview of the vulnerability of contingent valuation and stated choice methods to several types of bias, which shows that the indirect way of stating WTP in the stated choice method reduces most biases considerably. Also standard gamble and risk trade-off do not ask respondents to state their WTP directly, which is likely to reduce bias. On the other hand, people may have difficulties answering questions about lotteries on health and risk of death in standard gamble studies, resulting in bias related to non-response and protest behaviour. Furthermore, the reliability of indirect WTP methods depends on the reliability of the VSL from which the value of an injury is derived, and thus on the method used to estimate the VSL. Revealed preference methods can be regarded as more reliable than stated preference methods, because data on actual behaviour are used. However, other types of bias are introduced, in particular selection bias. The reliability of the QALY-method depends on the methods that are used to determine QALYs and the WTP for a QALY. QALY estimates obtained from standard gamble and trade-off methods are regarded as more reliable than those obtained from health rating methods. Only contingent valuation has been applied to determine the WTP for a QALY, which limits the reliability of the QALY-method.

5.3.3. Ability to handle injury diversity

The QALY-method is very detailed with respect to injury types and severity, which is a great advantage as compared to the other method. For example, Haagsma et al. (2012) developed a method for calculating the YLD of injuries using a classification of 39 injury categories. In contrast, the standard gamble studies included in Table 5.1 distinguish between 3 to 9 health states. In direct WTP and risk trade-off studies usually one broad definition of a road injury is used, sometimes even without specifying the health consequences of the injury.

5.3.4. Ethical issues

Monetary valuation of saving lives and injuries raises ethical concerns, in particular whether it is ethically acceptable to ask people to state amounts of money for saving lives and injuries and to make trade-offs between fatal and non-fatal risks. On the other hand, it is argued that trade-offs between money and injury risks are part of daily life. In that respect, the revealed preference method is less prone to ethical criticisms, because this method used data on choices people make in real life. Stated choice questions are closer to real life choices than the other stated preference methods, because several attributes are included in the choice, such as travel time, safety and costs in case of route choices. Direct trade-offs between fatal and non-fatal risk in standard gamble and risk trade-off, as well as the direct way of asking WTP in the contingent valuation method, are likely to raise more ethical concerns. Using QALYs introduces an additional ethical issue related to age. The valuation of lifelong injuries is higher for younger people than for elderly, because the calculation of QALY is based on the duration of the health loss. It is an ethical issue whether different valuations per age group can be used in cost-benefit analysis.

5.3.5. Practicality

CV, SG and RTO have strong advantages from a practical point of views. The design of the questionnaires is relatively simple, although several aspects needs considerable attention, such as the way of asking WTP (e.g. open-ended questions, payment cards or dichotomous choices; Pearce & Özdemiroglu, 2002), the baseline risk level, the size of the risk change, the payment vehicle and the description of (the health consequences of) an injury. Also the techniques for data analysis are relatively simple for these methods (see for example Persson (2001)), whereas SC requires more complex econometric modelling (Rizzi and Ortúzar, 2006). Regarding the QALY-method, standardized formats for determining health states, for example for EQ-5D, are available as well as straightforward methods for obtaining the WTP for a QALY such as contingent valuation. Applying QALYs in cost-benefit analysis is somewhat more complicated, because the value per QALY needs to be converted into a value per injury. This requires information about the number of QALY per road injury, which may not be readily available in many countries. The practical applicability of RP is limited because of the strong data requirements.

5.3.6. Summary

Table 5.3 gives an overview of the scores of the methods on each criterion, ranging from poor (-) to very good (++). The scores are based on the strengths and weaknesses of each method as discussed above with respect to each criterion. Overall, we can conclude that SC is favourable because of its theoretical basis, reliability and ethical acceptability. From that perspective, it is not surprising that all recent studies on monetary valuation of road injuries have applied this method. Besides the fact that SC is a relatively complex method requiring expertise on econometric modelling, a main weakness is the fact that SC cannot handle injury diversity. In that respect, the QALY-method has a great advantage above the other methods. Although the QALY-method uses sophisticated methods for quantifying (loss of) quality life, a main problem is the fact that CV is used for the monetary valuation of the health states which is known to be vulnerable for several types of bias.

Table 5.3: Assessment of WTP-methods

	Theoretical basis	**Reliability**	**Injury diversity**	**Ethical**	**Practicality**
Direct WTP					
- CV	+	-	-	+/-	+
- SC	++	+/-	-	+	+/-
- RP	+	+	+/-	++	-
Indirect WTP					
- SG	+/-	+/-	+/-	+/-	+
- RTO	+/-	+/-	+/-	+/-	+
- Health rating	-	-	+/-	+	++
QALY	+/-	-	++	-	+

Combining SC and QALYs can be a promising direction for future research which unites the strong elements of both approaches. This implies that a two-step approach is needed, as is the common practice in studies on the WTP for a QALY. In the first step, the quality of life loss resulting from road injuries is measured, for example using the EQ-5D instrument, and in a second step the WTP for (preventing) this quality of life loss is measured in a stated choice experiment (instead of using CV which is the current practice). It is recommended to further explore this novel approach.

5.4. Discussion

This paper shows that monetary valuations of preventing road injuries as found in the literature show large variations. This complicates choosing a value for practical applications such as cost-benefit analysis and assessments of the socio-economic costs of road crashes. A European study on the external costs of transport (ECMT, 1998) proposed to value serious and slight road injuries at 13% and 1% of the VSL respectively, based on values from the UK (Hopkin & O'Reilly, 1993; O'Reilly et al., 1994). Drawing on this study, subsequent European studies (e.g. Bickel et al. (2005) and Van Essen et al. (2019)) included the same values as a standard. In other parts of the world, the value of a serious injury is often set at 25% of the VSL as a standard, based as assessment of QALYs of serious road injuries in the US, Thailand and Hong Kong (McMahan and Dahdah, 2008). This estimate was used, for example, by GRSF (2020) to estimate the global costs of road injuries. These examples illustrate that the empirical basis for monetary valuation of road injuries used in practical applications is very limited and that these values are not based on recent stated choice studies. It is recommended to update the values that international studies recommend for practical applications using recent literature. However, updating the international recommended values is complicated due to the large variation in values found in the literature. Therefore, it is recommended to enlarge the empirical basis by conducting more valuation studies, preferably using (a combination of) stated choice and QALYs.

International reviews (Wijnen and Stipdonk, 2016; Wijnen et al., 2019) show that QALYs are barely used in road crash costs studies. This is remarkable because QALYs have been used extensively in the field of public health and road safety applications can benefit from this knowledge and data. For example, a standard methodology is available to calculate the YLD of (road) injuries including default values on disability weights and injury duration for 39 injury categories (Haagsma et al., 2012). Furthermore, QALY are particularly useful for cost-benefit analysis of interventions which have an impact on injury severity. Values per serious or slight injury are not sufficient in that case, because the number of injuries may not change. Instead, the impact on injury severity should be estimated and monetized, preferably using QALYs. However, determining a monetary valuation of a QALY, which is needed for applying QALYs in road crash cost assessments and cost-benefit analysis, is challenging given the large variation in QALY-values. Attempts have been made to establish standardized values (Hirth, 2000; Neumann et al., 2014). However, these studies show that the large variation in QALY-values is an impediment for setting one single value. In the absence of scientific consensus on a standard value of a QALY, if it is possible at all to determine such a value, standard values per QALY as determined by health authorities for economic assessments of treatments could be used, provided that they are based on relevant WTP studies. It should be taken into account that the latter is often not the case (Marseille et al., 2014; Nimdet et al, 2015).

Worldwide, the number of serious road injuries is estimated to be 15 to 38 times higher than the number of fatalities (WHO, 2022). This implies that a value of a prevented serious injury of 3% to 6% of the VSL would make the value of preventing all road injuries (also referred to as the 'cost' of non-fatal injuries) equal to the value of preventing all road fatalities ('cost' of fatalities). Most studies in our review found larger values of preventing a serious road injury, which indicates that the total cost of serious injuries is larger than the cost of fatalities. Consequently, preventing non-fatal road injuries can be considered as at least as relevant as preventing fatalities from an economic point of view. This supports the case for directing policy attention and budget to preventing non-fatal injuries.

5.5. Conclusions

This paper reviewed methods for monetary valuation of preventing non-fatal road injuries and the values found in the literature. Based on the assessment of the methods, we conclude that stated choice is the preferred method, in particular because of its theoretical basis and the indirect way of eliciting WTP which reduces bias and ethical concerns. However, the ability of stated choice to include different injury types and severities is very limited. Only the QALY method is very well suited to assess a wide range of injuries, but suffers from other limitations including theoretical concerns. Combining stated choice and QALYs can be a promising direction for future research as this would combine the strengths of both approaches.

Despite the importance of non-fatal injuries in road safety policy making and road crash costs, the number of direct and indirect WTP-studies on non-fatal road injuries is very limited. The values per prevented serious injury found in these studies show large variation, which complicates determining a standard value for usage in cost-benefit analysis and road crash cost assessments. The same applies to values per QALY: the range of values which are relevant in the context of road safety, is very wide. It is recommended to enlarge the empirical basis of the monetary valuation of non-fatal road injuries by conducting more valuation studies, preferably using (a combination of) stated choice and QALYs, and to update the values that international guidelines recommend for cost-benefit analysis and road crash costs assessments.

Despite the large range of values of a prevented serious injury, our results indicate that preventing serious road injuries is at least as relevant as preventing fatalities from a socio-economic point of view, due to the much larger number of non-fatal injuries.

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6. Benefits and costs of non-fatal road injury reduction: a methodology and applications to vehicle safety

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Submitted

Abstract

Cost-benefit analysis (CBA) is a valuable input for road safety policy making, but the standard CBA-approach often fails to include the benefits of preventing non-fatal injuries accurately. This paper presents a new methodology for assessing these benefits with applications to vehicle safety systems. We developed a CBA-methodology for road safety interventions using standard CBA-principles and added two novel elements. Firstly, a detailed classification of injury types is used and injury (severity) reduction is translated into quality of life gains (QALYs) and monetary benefits using standardized data. Secondly, a linkage with human body model (HBM) simulations is established to obtain injury probability changes. The methodology is applied to three case studies: an active headrest, autonomous emergency braking systems and an improved tram front. The improved CBA-methodology results in a more detailed and accurate assessment of the benefits of preventing non-fatal injuries, as compared to standard CBA which does not take into account the type of injury and its severity. The case studies illustrate that the methodology is capable of including the specific injury prevention benefits of vehicle safety systems and that standard CBA would under- or overestimate these benefits. It is concluded that the novel elements added to standard CBA improve the accuracy of CBA. Usage of HBMs is demonstrated as an efficient way to obtain data on the safety impacts of vehicle systems as it enables benefit assessments of systems for which field data are not (yet) available. Limited availability of case-specific data on crash risks and costs of safety systems is identified as a main challenge for CBA of vehicle safety systems. The methodology and standardized data are embedded in a practical calculation tool, aimed at supporting decision making on road safety interventions by road safety professionals, in particular those who have specific interest in vehicle safety.

Keywords: cost-benefit analysis; injury; road safety; vehicle; QALY; human body modelling

6.1. Introduction

Cost-benefit analysis (CBA) of road safety measures and programs is a valuable input for road safety policy making (Bliss and Breen, 2009). Stakeholders in the field of road safety, such as governmental organizations, vehicle industry, NGOs and others, can benefit from cost-benefit analysis, as it helps to justify road safety investments and prioritizing road safety investments (Hauer, 2011). Applying cost-benefit analysis to road safety interventions has been advocated by academics (for example Evans, 2009; Asplund & Eliasson, 2016) as well as by governmental and non-governmental organizations who aim to improve road safety (ADB, 2003; AASHTO, 2010; EC, 2014; PIARC, 2015). The applicability of cost-benefit analysis in the context of road safety is not undebated though, in particular with respect to monetization of saving lives (Elvik, 2001; Hauer, 2011). The feasibility of conducting cost-benefit analysis of road safety measures has been demonstrated in numerous studies. Daniels et al. (2019) made cost-benefit analyses of 29 road safety measures in different countries or regions, including infrastructure improvements, legislation, enforcement, education, post-crash treatment and vehicle equipment. Cost-benefit analyses of vehicle safety improvements were conducted in several European research projects (Hynd et al., 2015; Scholliers et al., 2020).

In all these cost-benefit analyses the estimation of the benefits is based on the number of crashes or casualties prevented and a monetary valuation per crash or casualty. Guidelines for cost-benefit analysis in the context of road safety adopt the same approach (AASHTO, 2010; PIARC, 2015). Usually, a few severity categories are used to classify the crash outcome, typically fatal, injury (sometimes split into serious and slight) and property damage only crashes. These standard CBA practices are not always well suited for assessing road safety interventions for two reasons, which both concern the level of aggregation of the injury prevention benefits. Firstly, several road safety measures are aimed at preventing specific types of crashes (e.g. run off road crashes or rear-end car crashes) which result in specific types of injuries (e.g. whiplash associated disorders in rear-end car crashes). The costs of the injuries, and therefore benefits of preventing them, are different for each type of injury. Secondly, the standard CBA methodology is not able to assess the impact on injury severity adequately, because the standard injury categories are too broad. For example, a serious injury is often defined as an injury requiring hospital treatment during at least 24 hours or with an overnight stay (Schoeters et al., 2020). If an intervention reduces the severity of a serious injury, but still hospital treatment during more than 24 hours is required, there is no impact on the number of serious injuries. Consequently, the standard approach in cost-benefit analysis, which is based on the impact on the number of injuries, fails to include the benefits of reduced injury severity in such cases.

This paper presents a methodology for conducting socio-economic cost-benefit analysis of road safety interventions, which addresses these two issues. We concentrate on vehicle safety systems, because several of these systems are aimed at preventing specific types of crashes and injuries and/or at reducing the injury severity. Examples include autonomous emergency braking systems, adaptive cruise control and whiplash prevention systems. We add two novel elements to the standard CBA approach. Firstly, the methodology uses a detailed classification of injury types and translates the injury (severity) reduction into quality of life gains and monetary benefits. Secondly, a linkage with human body model simulation results is established. These models are able to simulate the impacts of a collision on the human body and to produce the changes in probabilities of specific injuries. Evidence on the effectiveness of vehicle safety systems in terms of reduced probabilities of specific injuries is very limited and most cost-benefit analyses rely on data on crash avoidance (see e.g. Yue et al., 2018). In the presented cost-benefit methodology, results from human body models are used to fill this data gap. The methodology is illustrated by three case studies of vehicle safety improvements.

6.2. A methodology for cost-benefit analysis of vehicle safety systems

6.2.1. Overview of the methodology

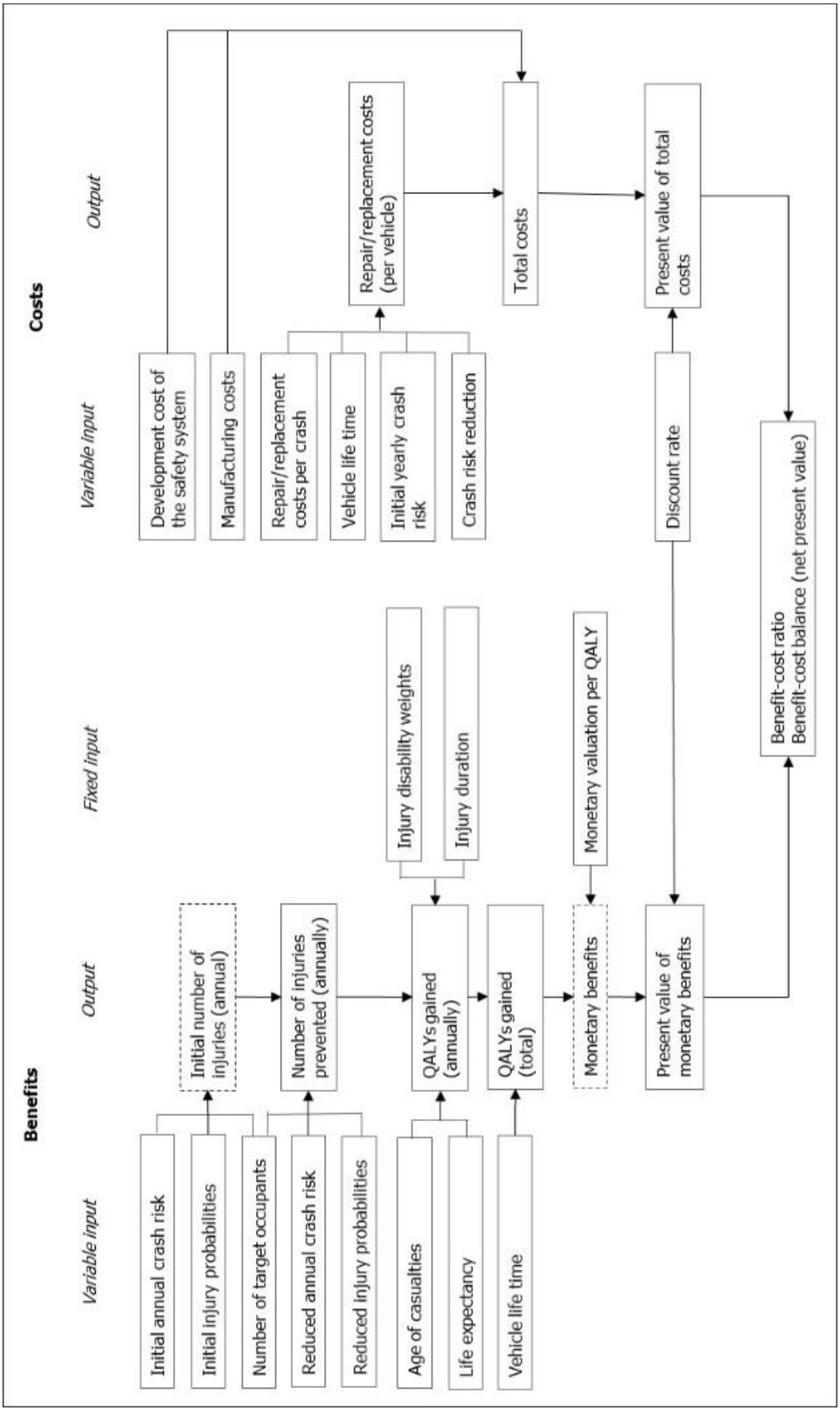
Figure 6.1 depicts a schematic overview of the methodology we present in this paper for conducting cost-benefit analysis of vehicle safety systems. The methodology follows the standard principles of cost-benefit analysis (see e.g. Boardman et al., 2011). This means, among others, that a welfare economic approach is adopted and that costs and benefits are assessed from a societal perspective and expressed in monetary terms. On the benefit side, the monetary benefits of reducing injuries or injury severity are calculated using information on changes in crash risk and injury probability, which are translated into Quality Adjusted Life Years (QALYs) and monetary terms. On the cost side, the costs of introducing new vehicle safety systems are calculated, including development, manufacturing and repair or replacement costs.

A distinction is made between variable and fixed inputs. Variable inputs are different for each case, as they depend on the vehicle safety system under consideration and the country, whereas fixed inputs are the same for each system. The methodology is aimed at calculating the safety impacts, cost and benefits per vehicle. Each element of the methodology is discussed in more detail below. The methodology is embedded in an open source practical calculation tool which has been developed in MS Excel (available at https://openvt.eu/). To the extent possible, standardized European values, such as injury disability weights, monetary valuations and the discount rate, are included in the tool and applied in the case studies presented in this paper. For further details, including all formulas to calculate the costs and benefits, see Bützer et al. (2022).

6.2.2. Injuries prevented

The first step in calculating the safety benefits is the estimation of the number of injuries prevented by a vehicle safety system. To address the fact that road injuries are very diverse and that most vehicle safety systems prevent specific types of injuries, our methodology uses the EUROCOST injury classification system which distinguishes 39 injury groups (Lyons et al., 2006). For this classification system, data required for calculating QALYs is available (Haagsma et al., 2012; discussed below), which is a prerequisite for the purpose of this study. Such data is not systematically available for other, more detailed, classification systems such as the International Classification of Diseases (Haagsma et al., 2012). We extend the EUROCOST injury classification by distinguishing between left and right body parts if relevant, because injury probabilities can be different for left and right body parts which is reflected in the results from human body models. In addition, in two case studies we distinguish between severity categories for some injury groups, based on the Abbreviated Injury Scale (AIS) (see Section 6.4).

Figure 6.1: Overview cost-benefit calculation methodology.



The number of injuries prevented is calculated as the difference between the number of injuries (by injury group) before and after implementation of the vehicle safety system. The annual number of injuries per vehicle is calculated using crash risk (annual number of target crashes per vehicle) and the probability of an injury (by injury group) if a crash occurs, before and after implementation. Additionally, the number of road users the safety systems affect (target road users) is needed, as some systems are aimed at preventing injuries for one road user (e.g. a passenger airbag) while other systems are aimed at more than one road user (e.g. emergency braking systems).

6.2.3. QALY gains

The next step in the benefit estimation is translating the number of injuries prevented into QALYs, which is a measure of the impact on quality of life that combines injury severity and the duration of (the health impact of) an injury (Brent, 2014). QALY gains are calculated using disability weights that reflect the severity of the injuries and the impact on quality of life, and the duration of the loss of quality of life. To calculate QALY gains, we adopt a method developed by Haagsma et al. (2012), which has been applied successfully to non-fatal road injuries in previous studies (Polinder et al., 2015; Weijermars et al., 2018). They present a standardized methodology for calculating QALYs due to injuries, using disability weights for the 39 EUROCOST injury groups with a distinction between injuries treated only at the emergency department (ED) of a hospital and injuries that require hospital admission (HA). In addition, a distinction is made between the acute injury phase (first year after the injury) and lifelong health consequences. To calculate QALY gains related to prevention of lifelong injuries for the ‘average’ road casualty in the target group, information on the average age of the road users and age and gender specific life expectancy is used.

6.2.4. Monetary valuation

The monetary benefits of reducing road injury risk consist of reducing medical cost and productivity losses as well as monetary valuation of quality of life gains (Schoeters et al., 2020). Reductions of medical costs and production losses are calculated using the number of injuries prevented and values per injury type, separately for ED and HA injuries. In case of multiple injuries, only the injury with the highest production loss is included in the calculation, to avoid double counting of productivity loss of one person (mostly related to absence from work) due to different injuries at the same time. Quality of life gains can be monetized using a value per QALY. Monetary valuations of QALY are derived either from a stated preference study or from the value of a statistical life (Ryen & Svensson, 2014). In a stated preference study, people are asked about the amount of money they are willing to pay for a specific health improvement (see for example Gyrd-Hansen (2003) and Moradi et al. (2019)). Another approach is to derive the value of a QALY from the value of a statistical life (VSL) or from the value of a statistical injury (and indirectly from the VSL since most values of a statistical injury are derived from a VSL). The next section discusses the values found in literature and the value we use in this study.

6.2.5. *Costs of vehicle safety systems*

The cost of a road safety measure is the value, in monetary terms, of the resources used to produce the measure. These resources may include human manpower, machinery, land, and natural resources. With respect to vehicle safety systems, three types of costs can be distinguished:

1. Costs of developing the safety systems,
2. Costs of manufacturing the safety systems,
3. Costs of repairing or replacing the safety systems that have been deployed in crashes (e.g. airbags).

Usually, market prices are assumed to reflect the value of the resources used for developing, manufacturing and repairing or replacing safety systems. Development costs include the costs of research and technological innovation. Estimating these costs, which are incurred by the car manufacturer before the system is ready for the market, is difficult as they may be part of general innovation processes. However, these costs do not need to be estimated separately because development costs will be incorporated into the market price of vehicles having the system. Repair of replacement costs are dependent on crash risk and vehicle lifetime.

6.2.6. *Socio-economic return*

The net present value (NPV) and the benefit-cost ratio (BCR), (that is the difference, and ratio respectively, of the present value of the benefits and the present value of the costs), are calculated as indicators of the socio-economic return of the implementation of vehicle safety systems. A positive NPV or BCR greater than one indicates that the safety system is cost-beneficial from a socio-economic perspective. Present values are calculated using a social discount rate. The European Commission recommends 3% for non-Cohesion countries and 5% for Cohesion countries (EC, 2014). Alternately, official national discount rates can be used for country-specific case studies.

6.3. Data

6.3.1. *Crash risk*

For the calculation of safety benefits, detailed and case-specific information on crash risks and injury probabilities is needed. Crash risk data should refer to the crashes the safety systems are targeting, that means which are prevented by the safety system (in case of active safety systems) or crashes with reduced injury probability due to the safety system (passive safety systems). Potential data sources are national or international crash databases (e.g. the CARE database), insurance data and naturalistic driving studies (e.g. the European UDRIVE study; Nes et al., 2019). A limitation of crash databases is the fact that they are mostly based on police reports, which is known to result in significant underreporting (Derriks & Mak, 2007). Also, insurance data suffer from underreporting, because a damage claim is not always submitted to an insurance company. Moreover, insurance data are mostly not publicly available. In naturalistic driving studies, data acquisition system in cars continuously collect data on the driving, such as speed, lane position and video views (forward, to the rear, and the driver's face and hands). A limitation is that the number of crashes is too low to be able to calculate crash risks (Dozza, 2020). In the case studies presented in the next section, we use data from different sources since the suitability of databases depends on the crash risk under consideration in each case.

6.3.2. Injury probabilities

Injury probabilities are obtained from finite element (FE) human body models (HBMs). FE HBMs have been developed as a virtual addition to crash-test dummies, which have limitations with respect to age, gender and size representation and predicting location-specific injuries (Yang, 2018). FE HBMs are able to predict injury risks resulting from road crashes in more detail, e.g. with respect to injury type, body region and human characteristics, by simulating the impact of a crash on the human body. The last decades, several models have been developed, and recent models address specific human properties such as gender and size (Linder & Svedberg, 2019). FE HBMs are a useful source of information for cost-benefit analysis of safety systems as they can deliver data on the impact of safety systems in terms of injury probabilities. FE HBMs can replace in-depth analysis of crash and injury data, which is very time-consuming and often beyond the scope of cost-benefit studies of road safety programs. Moreover, HBMs can predict injury risk reductions of safety systems which are recently, or even not yet implemented, and for which there is no field data yet. In this paper the ViVA+ HBMs (John et al., 2021) are applied in the case studies, which are further explained in Section 6.4.

6.3.3. QALY gains

To calculate QALY gains, we use standardized disability weights for the 39 EUROCOST injury groups that are available from Haagsma et al. (2012), separately for ED and HA injuries as well as for the acute injury phase (first year after the injury) and lifelong health consequences.[15] In addition, for each injury group the probability of lifelong health consequences is available. Furthermore, we use data on the proportions of ED and HA casualties for each injury group which were provided by the Dutch Consumer Safety Institute for the purpose of this study. These proportions are based on data from 13 hospitals in the Netherlands. In addition, case-specific and country-specific data on the average age of target road users and life expectancy are used to calculate QALY gains from preventing lifelong health consequences.

6.3.4. Monetary benefits

Information on medical costs and productivity loss is available from the Dutch Cost of Injury Model, which uses data from 13 hospitals in the Netherlands and patient follow-up survey (Polinder et al., 2016). For the purpose of this study, the medical costs and productivity losses for ED and HA road casualties by injury type were provided by the Dutch Consumer Safety Institute, which developed and maintains the model. The average medical costs are €2.128 and €10.918 for ED and HA casualties respectively, and the productivity loss €3,863 and €47,000

[15] Note that the method developed by Haagsma et al. (2012) concentrates on calculating DALYs (Disability Adjusted Life Years). Since DALYs can be seen as negative QALYs (Brent, 2014), QALYs gains are interpretated as DALY losses.

respectively.[16] The latter figure is the standardized European figure of productivity loss per serious injuries during all remaining life years as determined by Wijnen et al. (2017). This figure is differentiated by injury group using the data from Dutch Cost of Injury Model, which only refers to productivity loss in the first year after the injury.

A standard value of a QALY is derived from the literature. Based on a literature review, Wijnen (2021) gives an overview of monetary values of a QALY which are relevant for road safety applications. The range for values found in the 18 selected studies is extremely wide: €1,355 to €386,173 per QALY (2019 price level). The median values were €16,259 for all studies and €20,125 for European studies. Deriving QALY values from the VSL yields values which are more than five times higher than values from preference studies (Ryen & Svensson, 2014).

Based on a survey on road crash costs in 31 Europe countries, Wijnen et al. (2017) determined a standard value of human costs of serious injuries at €250,000. A Dutch study shows that the number of QALY lost due to a serious injury is estimated at 2.1 QALYs (Weijermars et al., 2016), which results in a value per QALY of about €120,000.

Based on this literature, a plausible range of the value per QALY is €20,000-€120.000. A default value of €70,000 is used in this study.

6.3.5. Costs of vehicle safety systems

Information on the costs of developing, manufacturing and repairing or replacing vehicle safety systems is an essential, case-specific input. Estimating the costs of safety systems on the basis of market prices can be problematic if systems are not sold separately or if they are installed in vehicles by default, which is the case for most systems. In those cases, the costs could be estimated using educated guesses from experts in the field, such as vehicle manufacturers and suppliers of safety systems. Several cost-benefit studies have estimated the costs of a range of vehicle safety system, mostly based on information obtained from the vehicle industry (e.g. Hynd et al., 2015; Scholliers et al., 2020). In the case studies presented in the next section, we use data from different sources to obtain cost information of the vehicle system which is assessed in each case.

6.4. Case studies

To illustrate the methodology, CBAs of three vehicle safety systems aimed at preventing specific crash or injury types, or at reducing injury severity, are presented:

1. An active headrest in passenger cars aimed at reducing Whiplash Associated Disorders (WAD). WAD are frequently reported in rear-end crashes. Annually, it is estimated that around 800,000 European Union citizens suffer from WAD (Linder et al. 2013). Although WAD are not life-threatening, they can result in long-term health consequences as well as permanent disabilities (Kullgren et al. 2007; Krafft, 1998; Nygren, 1983). By pushing the headrest forward in case of a collision, active headrests

[16] All monetary values are in price level 2020 unless stated otherwise.

reduce the distance between the head and the headrest. This reduces the relative motion between the driver's or occupant's head and the torso that occurs during a rear-end impact, and reduces the risk of WAD (Olsson et al., 1990; Jakobsson et al., 2008).

2. Autonomous Emergency Braking (AEB) for pedestrians and cyclists, which is an in-vehicle system aimed at preventing collisions with a pedestrian or a cyclist by automatically applying the brakes (Saadé, 2017). AEB can mitigate the injury consequences of a crash (if not avoided) by reducing the impact speed (Schachner et al., 2020). A major part of pedestrian and cyclist fatal injuries is caused by collisions with a car: 68% of the 51,300 pedestrians and 53% of the 19,450 cyclists killed in the period 2010 to 2018 on EU roads (Adminaité-Fodor & Jost, 2020). Several studies have shown that AEB is an effective system to reduce car-pedestrian and car-cyclist collisions, although large differences in the effectiveness were found (Saadé, 2017). Pedestrian and cyclist AEB systems are assessed in current European New Car Assessment Programme (Euro NCAP) assessments and therefore have gained increasing importance in the last few years.

3. An improved tram front with softer front skirt attachments aimed at reducing injury severity of tram-pedestrian collisions. The front is made softer by beam elements that connect the vehicle with the front skirt panels. Currently, trams run in 235 cities in Europe with a continuously increasing tram network length (SCI, 2022). Therefore, the number of tram crashes will probably increase and currently a tram is expected to be involved in one or more crashes during its lifetime (Lackner et al., 2022). Pedestrians are involved in a major proportion of tram crashes and about a third of the pedestrian injuries are severe (Lackner et al., 2022). Improved tram fronts can reduce the severity of these pedestrian injuries (Weber et al., 2015; Lackner et al., 2022).

6.4.1. Crash risk

The target crashes in the three cases are rear-end car crashes, car-pedestrian and car-cyclist crashes and tram-pedestrian crashes respectively. For car-pedestrian and car-cyclist crashes, data on the number of crashes (all severities) from the CARE database (EU-CARE, 2022) were analysed and combined with data on the number of registered passenger cars (taken from Adminaite-Fodor et al. (2021) and Adminaite et al. (2017)) to obtain injury crash risks per car. Different time spans were used for each case, depending on data availability in the CARE database.

National crash statistics, and thus the CARE data, are known to suffer from incompletes due to underreporting. This is particularly true for rear-end crashes because injury symptoms, e.g. WAD, do not occur directly after the crash and police may not be called. For that reason, we use insurance data for rear-end crashes. Data from the Swedish insurance company Folksam show that the annual risk (number of crashes per car) of a rear-end crash is 0.022 to 0.026 in the period 2000-2020. Assuming that two cars are involved a crash, the risk of an rear-end crash for the struck car is 0.013. Insurance data from AXA Switzerland show similar values: the annual risk for a liability rear-end collision is 0.015 per vehicle for cars, vans and trucks (average 2016-2020). These values are much higher than the crash risk obtained from the CARE data, which indicates that the latter suffer from a high underreporting rate. Based on the insurance data the upper risk value (0.015) is used for the active headrest case, because also the insurance data might suffer from some underreporting.

The CARE database does not include tram-pedestrian crashes. Data on these crashes are hardly available at the national level (COST, 2015), but they are available at the level of individual cities through data collection by tram or public transport operators. We use the city of Vienna as an example, as information needed for estimating injury probabilities (see below) was only available for this city. The tram-pedestrian crash risk in Vienna is 2.9 (number of tram crashes per million vehicle km; Lackner et al., 2022), the annual distance driven by trams is 23.1 million km (Lackner et al., 2022) and the number of daily running trams is 398 (Wiener Linien, 2019)), which implies that the annual number of crashes per tram is 0.169. Note that this risk concerns all types of tram-pedestrian crashes and that only part can be prevented by improved tram fronts, resulting in an overestimation. However, there is no data on the number of injuries due to collision of pedestrians with the tram front. Table 6.1 summarizes the crash risk data we apply in each case.

Table 6.1: Annual crash risks (number of injury crashes per vehicle and per million km driven) for the target crashes in the case studies. Sources: AXA insurance data (active headrest), authors calculations based on CARE database (AEB), Lackner et al. (2022) and Wiener Linien (2021) (improved tram front).

Case	Crash type	Geographical area	Period	Crash risk
Active headrest	Car rear-end	Switzerland	2016-2020	0.015
AEB	Car-pedestrian	14 EU countries	2012-2016	$0.40*10^{-3}$
	Car-cyclist	14 EU countries	2014-2016	$0.51*10^{-3}$
Improved tram front	Tram-pedestrian	City of Vienna	2014-2020	0.169

AEB is an active safety system, which reduces the crash risk. We estimated the crash risk reduction using a pre-crash tool developed within the VIRTUAL project based on the OpenPASS simulation platform, which is particularly aimed at assessing the impact of active safety systems (Schachner et al., 2020). It uses the road layout standard OpenDRIVE to derive participants' motion profiles in combination with accident data. Virtual testing scenarios were developed based on the conflict situation, collision point, speed of the vehicle and the pedestrian or cyclist and road condition (dry/non-dry). 61,914 and 72,035 scenarios were derived for car-pedestrian and car-cyclist collisions respectively. Taking into account the probability of the scenarios, it was found that 81,70% of the car-pedestrian collision and 53,80% of the car-cyclist collisions were prevented by AEB (see Leo et al. (2022) for further details).

6.4.2. Injury probabilities

The probability of injuries occurring in the target crashes in each case was obtained from HBM simulations, for situations with and without the safety system. Finite Element (FE) Human Body Models (HBMs), more specifically the ViVA+ HBMs for average males and females (VIVA+ 50F and 50M) which have been developed within the VIRTUAL project (John et al., 2021; Klug et al., 2023), were used to for these estimations. Different injury predictors were extracted from the simulations for each injury group, which are subsequently translated into injury probabilities using risk functions. In the active headrest case, for example, firstly the Neck Injury Criterion (NIC, in m^2/s^2) was calculated. Next, the probability of WAD was calculated using a risk function which specifies the relation between the probability of WAD and the maximum NIC value.

For the active headrest case, accident reconstruction simulations were conducted using an open-source Toyota Auris FE seat model and real-world accident data from Folksam, in order to evaluate the influence of different head to head-restraint distances on WAD2+. WAD2+ implies complaint and musculoskeletal sign(s) including decreased range of motion and point tenderness (Spitzer et al., 1995). Six different crash pulses, based on Folksam accident data, were simulated. Each model (VIVA+ 50F and 50M) was run with the same crash pulse in two different head to head-restraint distances (120 mm and 95 mm) to simulate the impact of an active headrest. Consequently, 24 simulations were performed. The probability of WAD2+ injury was calculated for the driver of the struck vehicle, who has a higher injury risk than the driver of the striking vehicle in two-vehicle rear-end crashes (Khattak, 2001). A risk function developed by Ono et al. (2009) was used to estimate WAD2+ injury probabilities. Further details can be found in Jakobsson et al. (2022).

For the AEB case, a conceptual AEB system based on previous studies (Barrow et al., 2018; Gruber et al., 2019; TRL et al., 2018) and a generic Sedan car front model, based on the generic vehicle models developed for the Euro NCAP certification of pedestrian models (Klug et al., 2017; Klug et al., 2019), were applied. In-crash simulations were performed using the VIVA+ pedestrian and bicycle HBM models (John et al., 2022) in different postures and the 50M and 50F anthropometry. For both baseline and AEB scenarios 50 in-crash simulations were conducted for males and females as well as for pedestrians and cyclists, resulting in a total of 400 simulations.

For the tram case, a generic tram front model with adjustable stiffness was used, which was designed in accordance with the geometrical recommendations for railways by the European Committee for Standardization (CEN/TC, 2020). The same pedestrian model as used in the AEB case was applied. Using the VIVA+ 50F and 50M models, simulations were conducted separately for males and females, for two positions of the pedestrian (middle of the tram and a 25% offset from the middle), nine impact velocities and for trams with and without the improved front, resulting in 72 simulations. The probability for different tram-pedestrian conflict situations was retrieved from crash data (Lackner et al., 2022). Further details can be found in Leo et al. (2022). The injury types predicted for the AEB and tram use case include concussion, rib fracture, hip fracture, femur shaft fracture, tibia fracture and knee ligament rupture, which were selected on the basis of an analysis of injury data (Bützer et al., 2020; Leo et al., 2021; 2019a; 2019b). Severity categories were used for concussion and rib fractures, based on the Maximum Abbreviated Injury Scale (AAAM, 2005). The results of the in-crash simulations were then processed with the help of the Open Source post-processing tool DYNASAUR, which include all relevant injury criteria, and a Jupyter notebook to establish an injury probability for different body regions for each in-crash simulation. For further details, see Leo et al. (2022).

Table 6.2 presents the resulting injury probabilities. Upper and lower values were estimated using the confidence intervals of the risk curves, if available. As expected, the probability of all injuries is reduced or there is a shift from higher to lower injury severity. High reduction rates are particularly found for femur shaft and tibia fractures in the AEB and tram cases, whereas the lowest reduction rates are found for knee ligament rupture (AEB case). A reduction in injury severity is particularly seen for concussion in the AEB pedestrian and tram cases as well as for rib fractures in the AEB cyclist and tram cases, where the probability of AIS4+ injury reduces stronger than the lower severity injury probabilities. AIS1 and AIS2 injury probabilities increase in some cases, indicating a shift from higher to lower severity injuries. Gender differences were particularly found for rib fractures in the AEB pedestrian case (where the shift from higher to lower severity is stronger for women), for femur shaft fractures in the AEB cyclist case (stronger injury probability reduction for men) and for knee ligament rupture in the AEB cases (stronger reduction for women). This is explained by gender differences with respect to anthropometry and cortical bone thickness.

Based on the injury probabilities and crash risks, the number of injuries prevented during the vehicle lifetime (assumed to be 15 years) is estimated at 0.045 in the active headrest and 0.040 in the AEB case (Table 6.3), implying that one injury is prevented if the safety system is installed in 22 and 25 cars respectively. The crash risk is much higher in the headrest case as compared to the AEB case, while the overall injury probability is higher in the AEB case. The number of injuries prevented by the improved tram front is many times higher (5.5 injuries per tram during the vehicle lifetime), due to a higher crash rate, higher injury probabilities (particularly as compared to the active headrest case) and a longer vehicle lifetime (assumed to be 30 years). Note that the injury reduction by the improved tram front is likely to be lower in other European cities due to the relatively high crash risk in Vienna (2.9 injury crashes per million vehicle km, versus a median value of 0.9 in 15 cities; Lackner et al., 2022).

Table 6.2: Injury probabilities (in percentages) before and after implementation of the vehicle system in three case studies and injury probability changes, obtained from human body model simulations.

		Male						Female						Probability change (best estimates)	
		Before			After			Before			After			Male	Female
		lower	best	upper	lower	best	upper	lower	best	upper	lower	best	upper		
Active headrest															
WAD2+			*60.1*			*39.3*			*60.6*			*42.0*		-35%	-31%
AEB pedestrians															
Concussion	AIS1		*8.1*			*6.3*			*7.2*			*8.0*		-22%	11%
	AIS2		*24.4*			*15.6*			*22.7*			*18.4*		-36%	-19%
	AIS4+		*38.9*			*14.2*			*46.1*			*15.4*		-63%	-67%
Rib fracture	AIS1		*14.7*			*4.9*			*13.9*			*12.0*		-67%	-14%
	AIS2		*8.6*			*5.3*			*8.3*			*2.7*		-38%	-67%
	AIS3+		*27.4*			*14.4*			*17.5*			*0.5*		-47%	-97%
Hip fracture	Left	7.0	*17.7*	31.0	2.0	*12.4*	27.0	16.0	*26.1*	38.0	8.0	*16.6*	28.0	-30%	-36%
	Right	10.0	*18.0*	29.0	2.0	*8.7*	19.0	37.0	*48.5*	58.0	7.0	*18.3*	31.0	-52%	-62%
Femur shaft fracture	Left	12.0	*18.4*	25.0	4.0	*9.8*	17.0	11.0	*17.1*	24.0	3.0	*6.8*	12.0	-47%	-60%
	Right	16.0	*26.4*	37.0	1.0	*3.2*	8.0	13.0	*23.0*	34.0	1.0	*3.3*	9.0	-88%	-86%
Tibia fracture	Left	2.0	*2.6*	5.0	0.0	*0.1*	1.0	0.0	*1.4*	5.0	0.0	*0.2*	2.0	-96%	-86%
	Right	2.0	*3.5*	7.0	0.0	*0.2*	2.0	1.0	*3.7*	10.0	0.0	*0.6*	3.0	-94%	-84%
Knee ligament rupture	Left		*98.2*			*94.2*			*92.1*			*83.1*		-4%	-10%
	Right		*99.6*			*96.9*			*99.0*			*93.9*		-3%	-5%
AEB cyclists															
Concussion	AIS1		*5.9*			*3.6*			*6.2*			*4.0*		-39%	-35%
	AIS2		*15.6*			*8.1*			*15.9*			*10.4*		-48%	-35%
	AIS4+		*11.7*			*4.3*			*16.6*			*9.0*		-63%	-46%
Other skull-brain injury			*23.6*			*10.3*			*23.2*			*14.2*		-56%	-39%
Rib fracture	AIS1		*8.6*			*5.6*			*10.7*			*4.6*		-35%	-57%
	AIS2		*4.1*			*4.7*			*2.1*			*2.9*		15%	38%
	AIS3+		*23.4*			*13.5*			*10.3*			*7.3*		-42%	-29%

Table 6.2 (continued)

		Male						Female						Probability change (best estimates)	
		Before			After			Before			After			Male	Female
		lower	best	upper	lower	best	upper	lower	best	upper	lower	best	upper		
AEB cyclists (continued)															
Hip fracture	Left	14.7	*23.0*	32.7	1.1	*6.2*	15.5	6.1	*15.2*	26.6	1.4	*10.7*	24.6	-73%	-30%
	Right	5.5	*16.9*	30.7	2.9	*13.1*	27.0	22.4	*40.1*	55.9	32.0	*57.7*	77.0	-22%	44%
Femur shaft fracture	Left	9.8	*13.9*	18.6	0.2	*1.1*	3.7	12.1	*17.4*	23.2	11.8	*15.5*	19.4	-92%	-11%
	Right	0.9	*3.1*	7.1	0.1	*0.6*	2.5	1.4	*5.9*	14.1	0.3	*3.7*	11.4	-81%	-37%
Tibia fracture	Left	0.0	*0.5*	2.3	0.0	*0.1*	0.6	0.0	*0.4*	2.2	0.0	*0.1*	0.8	-80%	-75%
	Right	10.9	*14.5*	18.6	1.4	*3.1*	5.8	21.2	*25.3*	29.5	4.8	*7.1*	9.8	-79%	-72%
Knee ligament rupture	Left		*78.3*			*72.9*			*90.0*			*71.2*		-7%	-21%
	Right		*93.0*			*93.2*			*94.0*			*76.6*		0%	-19%
Improved tram front															
Concussion	AIS1		*12.6*			*14.4*			*8.6*			*12.6*			
	AIS2		*38.9*			*37.2*			*34.3*			*35.0*		-22%	11%
	AIS4+		*30.2*			*17.7*			*41.6*			*26.2*		-36%	-19%
Other skull-brain injury			*35.3*			*31.6*			*36.2*			*31.0*		-63%	-67%
Rib fracture	AIS1		*4.1*			*7.3*			*5.3*			*6.5*		-67%	-14%
	AIS2		*3.8*			*6.0*			*4.1*			*7.5*		-38%	-67%
	AIS3+		*83.8*			*76.3*			*85.3*			*80.4*		-47%	-97%
Hip fracture	Left	45.4	*58.5*	69.7	9.4	*29.9*	49.0	71.3	*78.4*	84.5	40.3	*59.1*	73.6	-30%	-36%
	Right	8.0	*19.0*	31.0	1.3	*8.3*	19.1	34.4	*43.5*	52.1	2.5	*11.0*	22.9	-52%	-62%
Femur shaft fracture	Left	38.4	*52.3*	63.9	17.0	*31.2*	45.2	38.0	*45.3*	53.0	30.9	*37.1*	43.5	-47%	-60%
	Right	0.5	*2.8*	7.6	0.0	*0.6*	3.1	1.3	*6.2*	13.7	0.1	*1.3*	5.1	-88%	-86%
Tibia fracture	Left	1.2	*4.4*	10.5	0.2	*2.6*	8.0	21.6	*23.9*	28.0	1.2	*4.4*	9.8	-96%	-86%
	Right	23.7	*30.0*	34.5	1.2	*3.8*	8.3	18.3	*23.7*	29.5	10.7	*14.2*	17.9	-94%	-84%

6.4.3. QALY gains and monetary benefits

The injuries prevented in the three cases are translated into QALYs using the method developed by Haagsma et al. (2012) as described above. Haagsma et al. (2012) do not include data on lifelong injury consequences of WAD injury and concussion by MAIS-category. For these injury groups, we have added estimates on the proportion of lifelong injury consequences and long-term disability weights, based on literature and assumptions. Long-term injury consequences of rib fractures are not included due to lack of data. All input data are the same for left and right body parts. The Appendix provides an overview of the input data by injury group used for the QALY calculations. The average age of a road user is assumed to be 50 years (the average adult age in the EU as used as target age in the VIVA+ models (John et al., 2022)). A life expectancy of 81 years for men and 85 years of age for women at the age of 50 years is assumed, based on the life expectancy at birth (77.5 years for men and 82.3 for women) and at the age of 65 in the EU in 2020 (82.4 years of age for men and 86.0 for women (source: EUROSTAT). Based on Swedish data, see (Leo, et al., 2021), the proportion of male car occupants, pedestrians and cyclist are assumed to be 60%, 50% and 60% respectively. The number of QALYs gained is estimated at 0.021 and 0.049 in the active headrest and AEB case respectively (one QALY gained per 48 and 20 cars with the system respectively). Since the number of injuries prevented is the same in these cases, this indicates that AEB reduces more severe injuries, with more impact on quality of life, as compared to the active headrest. The improved tram front results in 18.6 QALY gained per tram, which is much higher than in the other two cases due to the higher number of injuries prevented. As a consequence, the monetary benefits of the improved tram front are many times higher than the benefits of the active headrest and AEB per vehicle (see Table 6.3).

6.4.4. Costs

Information on the cost of an active headrest is available from a cost-benefit analysis of two whiplash prevention systems (Eriksen et al., 2004), including an active headrest developed by SAAB. The costs of developing the whiplash prevention systems were estimated at about €5.1 million in the period 1994-2003 (2020 prices; prices in SEK 1994-2003 are translated in Euro 2020 using the harmonized price index for motor cars from Eurostat and purchasing power parities for individual consumption from Eurostat). Eriksen et al. estimated the number of vehicles with the improved seat at 250,000, so the development costs per vehicle are €20. The additional cost associated with manufacturing improved seats amounted to €15. Although some active headrests are designed to be reused without additional costs, we assume that repair is needed after deployment. Repair costs are estimated at €78 per seat (Eriksen et al., 2004). Based on an annual crash risk of 0.013 (see above), a vehicle life time of 15 years and a 3% discount rate, the repair costs per vehicle (RC) are estimated at €14. This results in a total cost of €49 per vehicle.

The cost of an AEB system depends on the type of system (radar and/or camera). Systems aimed at preventing collisions with pedestrians and cyclists require a camera or a combination of camera and radar. Hynd et al. (2015) estimate the cost of these systems at about €2,500-3,500. This range is in line with prices stated in a consumer test of six cars with AEB, including some cars with both cameras and radar (Lingner, 2015). We use €3,000 as a best estimate.

The cost of developing the improved tram front is estimated at €400 and the additional manufacturing costs, as compared to a conventional front, at €1,000 per vehicle, based on an expert judgment from the tram industry. Replacement costs in case of a crash are assumed to be equal to the manufacturing costs (€1,000 per vehicle), which translates into €3,804 on average during the vehicle lifetime.

6.4.5. Socio-economic return

The calculations of benefits and costs indicate that an active headrest has a high socio-economic return, as indicated by the BCR which ranges from 30.8 to 57.1 (best estimate 39.5; Table 6.3). This high ratio is explained by relatively very low costs, while the active headrest has a considerable impact on the probability of WAD. The benefits of AEB are estimated to be equal to the costs (best estimate), but in a less favourable scenario the benefits are slightly lower than the cost (lower BCR estimate 0.7). However, it should be noted that AEB is often part of a system with more driver assistance systems with additional benefits which are not included here. Moreover, conservative estimates of crash risks (based on reported crashes) were used in this case. The benefits and NPV of the improved tram front are many times higher as compared to the other cases (per vehicle) due to the higher lifetime and crash risk per vehicle (which is related to the much higher annual distance travelled per tram as compared to cars), resulting in a BCR of 180 (best estimate). Note that the BCR is likely to be lower in other cities than Vienna (but still very high as compared to the other cases) because of the higher crash risk in Vienna.

6.5. Discussion

In this paper we presented a standardized method for calculating the costs and benefits of vehicle safety system. New elements, as compared to the standard CBA-methodology in the context of road safety, are the usage of a detailed classification of injury groups and the calculation of QALY gains related to these injuries. Another novel element is the linkage with HBMs for the benefits assessment which, to the authors knowledge, has not been done in cost-benefit analysis before.

The case studies presented in this paper illustrate the feasibility of using the results of HBMs, in particular injury probabilities, as input for CBA in order to calculate safety benefits. Using HBMs is an efficient way to obtain this information as it avoids the need to conduct in-depth crash and injury analysis and enables assessing new vehicle safety system for which field data are not yet available. However, robust injury risk curves are required to translate the HBM simulation results into injury probabilities. Only injury types for which those are available can be considered in the CBA. Especially for low severity (AIS 1) injuries, reliable injury risk curves are not available due to a lack of data.

Table 6.3: Number of injuries prevented and QALY gains during the vehicle lifetime, present value of benefits and costs, net present value (NPV) and benefit-cost ratio (BCR). All values per vehicle. Monetary values in Euro 2020.

	Number of injuries prevented	QALY gains	Benefits (€)				Costs (€)	NPV (€)	BCR
			Medical cost reduction	Product-ivity gains	Quality of life gains	Total			
Active headrest									
Best estimate	0.045	0.021	134	665	1,158	1,957	49	1,907	39.5
Lower estimate	0.045	0.021	134	665	1,158	1,957	34	1,893	30.8
Higher estimate	0.045	0.021	134	665	1,158	1,957	64	1,922	57.1
AEB									
Best estimate	0.040	0.049	214	159	2,720	3,093	3,000	93	1.0
Lower estimate	0.036	0.037	170	110	2,082	2,362	2,500	-1,138	0.7
Higher estimate	0.044	0.062	264	208	3,459	3,931	3,500	1,431	1.6
Improved tram front									
Best estimate	5.546	18.585	46,275	40,150	849,952	936,377	5,204	931,173	179.9
Lower estimate	5.248	17.285	42,098	36,606	790,536	869,241	5,204	864,037	167.0
Higher estimate	5.617	19.100	48,577	42,590	873,504	964,671	5,204	959,467	185.4

The added value of the method presented in this paper, as compared to standard CBA, is twofold. Firstly, the valuation of prevented injuries is based on the type of injury and the related impact on quality of life. For example, AEB is aimed at preventing several types of injuries and reduces the probability of multiple injuries, whereas the active headrest is aimed only at reducing one injury type (WAD). This is reflected in the valuation per injured person, which is 444,000 Euro in the AEB case and 52,000 Euro in the active headrest case. Usually, such differences are not taken into account in standard CBA, which relies on standardized values per serious and slight injury (AASHTO, 2010; Hynd et al., 2015; PIARC, 2015; Daniels et al.., 2019; Scholliers et al., 2020). For example, Daniels et al. (2019) use a value of 330,000 Euro per prevented serious injury (2020 prices), based on a review of monetary values in Europe (Wijnen et al., 2017). Using this value would clearly overestimate the benefits of the active headrest and underestimate the benefits of AEB. Secondly, the methodology is able to take into account injury severity reduction. For example, in the tram front case the probability of AIS2+ concussion is reduced from 73% to 58% (weighted average male and female probabilities). In standard CBA, this is usually treated as a reduction of the probability of a serious injury and monetized using a value per serious injury. However, in this case the majority of concussion probability reduction, 14 percentage points, is an AIS4+ reduction, while AIS2 accounts for only 1 percentage point. Consequently, the standard injury severity categories in CBA (slight, serious and fatal injury) would underestimate the benefits in this case.

The methodological improvements presented in this paper concentrate on the estimation of the benefits of preventing of non-fatal injuries, since the method for including fatality reductions in cost-benefit analysis is more straightforward and undebated. The omission of the impact on fatalities in the case studies implies that the benefits of the vehicle safety systems are underestimated. However, this underestimation is expected to be limited. For example, the benefits of prevented fatalities by AEB are estimated at 14% of the benefit of non-fatal injury reduction. This calculation is based on the fatal crash risk of pedestrians and cyclists in collisions with cars from the CARE database, the same crash risk as reduction as used for non-fatal injury reduction and a monetary valuation of €2.5 million per fatality (harmonized European value from Wijnen et al. (2017) as used by Daniels et al. (2019), 2020 prices). Another source of underestimation of the benefits is the omission of the property damage only crashes prevented. Lack of reliable information on crash risk is a barrier for including this crash type in the cost-benefit analysis presented in this paper.

The methodology presented in this paper relies on standardized input data which can be used for any case study, such as data needed for calculating QALYs (disability weights, injury duration) and monetary valuations. Standard European values, such as monetary valuations and a discount rate, were applied in the case studies. For applications at the national level, country-specific data may be used instead to take into account differences in input values across countries. With respect to disability weights by injury severity, assumptions were made, as the disability weights presented by Haagsma et al. (2012) do not distinguish between MAIS categories. Developing these disability weights is recommended for further research.

In addition to the standardized inputs, case-specific data are needed, particularly crash risks and costs of safety systems, and obtaining these data can be challenging. Crash risk data should refer to risk of the specific types of crashes prevented by the safety system, which may not be available in sufficient detail. Moreover, crash data are likely to suffer from underreporting and preferably crash data should be corrected for that. If information on underreporting is missing, the benefits are likely to be underestimated and the CBA results should be interpreted as conservative estimates.

Data on costs is only publicly available for a limited number of safety systems, e.g. through European studies on costs and benefits of vehicle safety systems (Hynd et al., 2015; Scholliers et al., 2020). The automotive industry may be reluctant to provide such information for competitive reasons. Uncertainty about the costs (and other input data) can be captured by using upper and lower estimates in a sensitivity analysis, as illustrated in the case studies. In case cost information is not available at all, the break-even costs can be calculated, which is the maximum costs that would equalize the benefits and costs, as an alternative for the BCR. Experts could judge whether the real costs are likely to be lower than the break-even costs, which indicates whether or not the safety system is cost-beneficial.

6.6. Conclusions

The standardized method presented in this paper is a first effort to improve the standard CBA methodology in the context of road safety by using a detailed classification of injuries, applying

HBMs to calculate safety benefits and calculating the related QALY gains and monetary benefits. The case studies illustrate the feasibility of using HBM results as an efficient and promising way to obtain detailed information on injury risk reduction, although some requirements, such as availability of an appropriate risk function, may be challenging, especially for low-severity injuries. Furthermore, the case studies illustrate the added value of the methodology as compared to the standard CBA approach in the field of road safety. The methodology improves the accuracy of the benefit estimation by assessing the impact on specific injury types and using more detailed severity categories, whereas standard CBA relies on a cruder classification of road injuries (typically fatal, serious and slight) and monetary values per casualty. Limited availability of case-specific data on crash risks, taking into the issue of underreporting, and costs of safety systems is as a main challenge for cost-benefit of vehicle safety systems. Further research on including impacts on injury severity in the methodology, particularly calculating QALY gains of injury severity reduction, is recommended.

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Appendix: Input data QALY calculations

	Injury group	DW acute phase		Proportion HDR (%)	Proportion lifelong consequences (%)		DW lifelong consequences
		ED	*HDR*		*ED*	*HDR*	
1	Concussion	0.015	0.1	7	4	21	0.151
1a	Concussion AIS1	0.005	0.25	0	0	0	-
1b	Concussion AIS2	0.01	0.5	0	0	0	-
1c	Concussion AIS4+	0.03	2	30	8	50	0.151
2	Other skull–brain injury	0.09	0.241	74	13	23	0.323
3	Open wound on head	0.013	0.209	50	-	-	-
4a	Eye injury - left	0.002	0.256	36	0	0	-
4b	Eye injury - right	0.002	0.256	36	0	0	-
5	Fracture of facial bone(s)	0.018	0.072	24	-	-	-
6	Open wound on face	0.013	0.21	31	-	-	-
7	Fracture/dislocation/sprain/strain of vertebrae/spine	0.133	0.258	37	-	-	-
8	Whiplash injury/sprain of cervical spine	0.073	0.073	10	17	17	0.073
9	Spinal-cord injury	-	0.676	72	-	100	-
10	Internal-organ injury	0.103	0.103	63	-	-	-
11	Fracture of rib/sternum	0.075	0.225	61	-	-	-
11a	Fracture of 1 rib AIS1	0.025	0.1	0	-	-	-
11b	Fracture of 2 ribs AIS2	0.075	0.225	30	-	-	-
11c	Fracture of 3+ ribs AIS3+	0.15	0.5	90	-	-	-
12a	Fracture of clavicula/scapula - left	0.066	0.222	25	2	9	0.121
12b	Fracture of clavicula/scapula - right	0.066	0.222	25	2	9	0.121
13a	Fracture of upper arm - left	0.115	0.23	25	17	10	0.147
13b	Fracture of upper arm - right	0.115	0.23	25	17	10	0.147
14a	Fracture of elbow/forearm - left	0.031	0.145	22	0	8	0.074
14b	Fracture of elbow/forearm - right	0.031	0.145	22	0	8	0.074
15a	Fracture of wrist - left	0.069	0.143	13	0	18	0.215
15b	Fracture of wrist - right	0.069	0.143	13	0	18	0.215
16a	Fracture of hand/fingers - left	0.016	0.067	13	0	0	0.022
16b	Fracture of hand/fingers - right	0.016	0.067	13	0	0	0.022
17a	Dislocation/sprain/strain of shoulder/elbow - left	0.084	0.169	3	0	18	0.136
17b	Dislocation/sprain/strain of shoulder/elbow - right	0.084	0.169	3	0	18	0.136
18a	Dislocation/sprain/strain of wrist/hand/fingers - left	0.027	0.029	8	0	0	-
18b	Dislocation/sprain/strain of wrist/hand/fingers - right	0.027	0.029	8	0	0	-

19a	Injury to nerves of upper extremity - left	-	-	-	-	0	-
19b	Injury to nerves of upper extremity - right	-	-	-	-	-	-
20a	Complex soft-tissue injury of upper extremity - left	0.081	0.19	9	3	15	0.166
20b	Complex soft-tissue injury of upper extremity - right	0.081	0.19	9	3	15	0.166
21a	Fracture of pelvis - left	0.168	0.247	61	30	29	0.182
21b	Fracture of pelvis - right	0.168	0.247	61	30	29	0.182
22a	Fracture of hip - left	0.136	0.423	93	14	52	0.172
22b	Fracture of hip - right	0.136	0.423	93	14	52	0.172
23a	Fracture of femur shaft - left	0.129	0.28	80	46	35	0.169
23b	Fracture of femur shaft - right	0.129	0.28	80	46	35	0.169
24a	Fracture of knee/lower leg - left	0.049	0.289	50	23	34	0.275
24b	Fracture of knee/lower leg - right	0.049	0.289	50	23	34	0.275
25a	Fracture of ankle - left	0.096	0.203	31	12	35	0.248
25b	Fracture of ankle - right	0.096	0.203	31	12	35	0.248
26a	Fracture of foot/toes - left	0.014	0.174	16	8	39	0.259
26b	Fracture of foot/toes - right	0.014	0.174	16	8	39	0.259
27a	Dislocation/sprain/strain of knee - left	0.109	0.159	3	8	0	0.103
27b	Dislocation/sprain/strain of knee - right	0.109	0.159	3	8	0	0.103
28a	Dislocation/sprain/strain of ankle/foot - left	0.026	0.151	1	4	26	0.125
28b	Dislocation/sprain/strain of ankle/foot - right	0.026	0.151	1	4	26	0.125
29a	Dislocation/sprain/strain of hip - left	0.072	0.309	20	23	30	0.128
29b	Dislocation/sprain/strain of hip - right	0.072	0.309	20	23	30	0.128
30a	Injury to nerves of lower extremity - left	-	-	-	0	0	-
30b	Injury to nerves of lower extremity - right	-	-	-	-	-	-
31a	Complex soft-tissue injury of lower extremity - left	0.093	0.15	16	10	13	0.08
31b	Complex soft-tissue injury of lower extremity - right	0.093	0.15	16	10	13	0.08
32	Superficial injury (including contusions)	0.006	0.15	10	-	-	-
33	Open wound	0.013	0.093	11	-	-	-
34	Mild burn(s)c	0.055	0.191		0	0	-
35	Poisoning	0.245	0.245	19	0	0	-
36	Multitrauma	-	-	-	-	-	-
37	Foreign body	0.044	0.06	-	-	-	-
38	No injury after examination	-	-	-	-	-	-
39	Other and unspecified injury	0.111	0.212	13	-	-	-

DW: disability weight, ED: emergency department, HDR: hospital discharge register (overnight stay in hospital). Source: Haagsma et al. (2012) unless stated otherwise and except distinction between left and right body parts.

[1] All data are assumptions based on data for concussion (all severities).

[2] Assumed to be equal to the disability weight for the acute phase for ED patients, as a minimum estimate.

[3] Based on Sandberg Eriksen et al. (2004) who report, based on Swedish insurance data, that 10% of the WAD cases is serious.

[4] Estimates of the proportion of WAD that result in long-term health consequences range from 17% (Malm at al., 2008) to 50% (Teasell et al., 2020). 17% is used as a conservative estimate for both ED and HDR patients.

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7. Discussion and conclusions

7.1. Introduction

The aim of this thesis was to critically assess the literature and current practices for estimating the impact of road crashes and road safety measures on welfare and to improve and apply methods for estimating these impacts. Based on the gaps in the literature, four research questions were formulated to meet this aim:

1. Which methodologies are applied in individual countries to assess the welfare impact (or social-economic costs) of road crashes?
2. What is the size of this impact in individual countries and what is the breakdown of this impact into injury severity categories and cost elements?
3. What is/are the most appropriate method(s) to estimate the economic value of preventing non-fatal road injuries?
4. How can the estimation of the benefits of preventing non-fatal injuries in cost-benefit analysis (CBA) be made more accurate and take into account impacts on specific types of injuries and injury severity?

A combination of different research methods was used to answer these research questions, in particular literature reviews on the social costs of road crashes and monetary valuation of preventing non-fatal injuries, a survey among experts on road crash costs in European countries, a case study on the social costs of road crashes in middle-income country (Kazakhstan) and the development of a CBA-methodology with novel elements with respect to non-fatal injury prevention. Following welfare economic theory, a broad definition of welfare was applied, which implies, among others, that intangible impacts of road crashes, such as impact on quality of life, are explicitly taken into account. This chapter presents and discusses the answers on the four research questions as well as the implications for policy making and future research. Finally, some strengths and limitations of this research are discussed.

7.2. Findings on the research questions

1. Which methodologies are applied in individual countries to assess the welfare impact (or social-economic costs) of road crashes?

Three main valuation methodologies are available in the literature to estimate the social costs of road crashes: the restitution costs method, human capital method and willingness to pay (WTP) method. Each method is aimed at economic valuation of different welfare impacts: the restitution costs method at medical costs, property damage and administrative costs, the human capital method at production loss, and the WTP method at human costs., which are the intangible costs of loss of quality of life and life years. Consequently, a combination of the three methods is needed to capture all social costs.

The international review of cost studies (Chapter 2) and the survey among experts on road crash cost in European countries (Chapter 3) show that the restitution costs and the human capital method are generally applied to calculate the corresponding costs mentioned above. However, about half of the European countries as well as 30% of the high-income countries and all low- and middle-income countries included in the literature review do not adopt the WTP method. This is an important omission in road crash cost estimates in these countries, because a valuation of road injuries based on WTP is an essential element of an assessment of the welfare impact of road crashes if a broad definition of welfare, based on welfare economic theory, is adopted. The analyses presented in chapters 2 and 3 show that other methods are used instead in these countries to estimate the human costs. In particular the restitution costs method is applied, which means that human costs are estimated on the basis of financial compensation paid to road casualties or their relatives. These values are found to be much lower than values based on WTP.

No large differences between countries were found with respect to the main cost components included in cost studies (medical costs, production loss, human costs, property damage and administrative costs). However, differences were found at a more detailed level (within the main components), for example regarding loss on non-market production (voluntary work, work on black markets), damage to infrastructure and legal costs. Avoidance costs were not included in any country included in the reviews presented in this thesis. These are the costs resulting from adapting travel behaviour because of perceived safety levels, such as changing travel mode, route, destinations, or the decision whether or not to travel at all.

2. What is the size of this welfare impact in individual countries and what is the breakdown of this impact into injury severity categories and cost elements?

Estimates of the welfare impact of road crashes, or the social costs of road crashes, show large differences between countries. The impact is estimated at the equivalent of 0.4 to 6.0% of gross domestic product (GDP), as shown by the reviews presented in chapter 2 and 3. The differences between countries are mainly explained by the differences in the methodologies used to estimate the costs as discussed above. Particularly the method used for estimating human costs (WTP versus other methods) influences the size of the costs, because human costs have a large share in the total costs (discussed below).

In the case study presented in Chapter 4, the social costs of road crashes in Kazakhstan were estimated at the equivalent of 3.3% of GDP. This should be considered as a lower limit because conservative estimates of the number of road casualties were used. This case study indicates that the costs of road crashes in low- and middle-income countries are likely to be at the higher end of the range of costs estimates found in chapters 2 and 3, if all major cost components are included. This requires a combination of valuation methods (including WTP), as applied in this case study.

Serious injuries have a major share in the social costs of road crashes. According to the international review of cost studies (chapter 2), this share is on average about 50% in the total costs, while fatalities account for about a quarter to a third of the costs. The remainder of the costs is related to property damage only (PDO) crashes. The survey on road crash costs in European countries (chapter 3) confirms that the costs of serious injuries largely outweigh the costs of fatalities: the share of serious injuries in the total road crash costs is 2.4 times higher than the share of fatalities. However, the distribution of the costs among severity categories varies considerably between countries, which is likely to be partly explained by differences in crash reporting rates at each severity level. Furthermore, a large proportion of European countries (44%) does not include PDO crashes, which implies an important underestimation of the total costs.

Human costs have a major share in the total costs of road crashes: they account for 40% of the total costs on average in the countries included in international review (Chapter 2). This proportion is influenced by the method used to estimated human costs. In countries where WTP is applied, the average proportion is 54%, while it is only 18% in the low- and middle-income countries which do not adopt WTP. The survey in European countries (Chapter 3) shows that the human costs per fatality are much higher (€1.2 million and higher, 2015 prices) if based on WTP than values based on other methods (less than €0.1 million except one value of 0.6 million, 2015 prices). Human costs make up a large part of the costs per casualty if based on WTP: 54-94% of the costs of a fatality and 51-91% of the costs of a serious injury in European countries. The high proportion of human costs is confirmed by the case study in Kazakhstan where these costs were found to account for 80% of the total crash costs. Other relatively large cost components are property damage (particularly in LMIC: 39% of total costs on average) and production loss. Medical costs and administrative costs are relatively small.

3. What is/are the most appropriate method(s) to estimate the economic value of preventing non-fatal road injuries?

Eight different WTP-methods for monetary valuation of preventing non-fatal road injuries were identified in the literature review presented in Chapter 5. Based on the assessment of these methods using five evaluation criteria, stated choice (SC) was found to be the preferred method. In SC surveys, respondents are asked to make choices between several situations (mostly travel routes), which are different with respect to safety, travel costs and other attributes such as travel time. SC is rooted in random utility theory and has a stronger theorical basis than most other methods. Due to its focus on trade-offs that individuals make, SC is less prone to several types of bias (for example related to the survey design) than other stated preference methods. Moreover, SC is less associated with ethical concerns, because it uses data on choices people make in real life instead of asking people in a more direct way how much they are willing to pay for preventing injuries. As compared to revealed preference methods, SC (like other stated preference methods) has the practical advantage of not being dependent on the availability of data on actual behaviour.

A main limitation of SC is the fact that only a few types of injuries can be assessed and monetized. The QALY (Quality Adjusted Life Years) method, which concentrates on quality of life changes, is the only method which is capable of deriving a monetary values of a large range of injury types and severities. By combining SC and the QALY-method, the strengths of both approaches can be merged and this combined approach could produce detailed monetary values of non-fatal injuries with a strong theoretical basis. No such studies were found in the literature, however.

The WTP-methods which were assessed in Chapter 5 are aimed at the valuation of (loss of) quality of life. To calculate medical costs and production loss resulting from road injuries, the most suitable methods are the restitution costs and human capital method respectively (see above). These methods are generally applied and they are relatively undebated.

4. How can the estimation of the benefits of preventing non-fatal injuries in cost-benefit analysis (CBA) be made more accurate and take into account impacts on specific types of injuries and injury severity?

In the standard approach of CBA of road safety measures, the benefits of preventing non-fatal injury are estimated on a highly aggregated level, which distinguishes (at most) only between serious and slight injuries. This implies that the benefits of road safety measures, if they are aimed at preventing specific injuries or at reducing injury severity, are not taken into account accurately. The CBA-methodology developed in Chapter 6 shows that this omission can be addressed by using a detailed injury classification and injury severity categories. The EUROCOST injury classification into 39 injury groups and the Abbreviated Injury Scale (AIS) were applied to assess the benefits of preventing non-fatal injuries or reducing their severity. To obtain the data needed for this disaggregated approach, specifically data on the impacts of road safety measure on specific injuries and on their severity, results of human body model (HBM) simulations was used. Integrating HBM results in CBA was shown to be an efficient way to obtain the required detailed information on the impacts of safety interventions for which field data are not (yet) available.

The monetary values of a prevented slight or serious injury as used in standard CBA are not applicable if road safety measures have impacts on specific types of injuries or on injury severity. In that case the impacts on non-fatal injuries can be monetized more precisely by expressing the specific injury impacts in terms of Quality Adjusted Life Years (QALYs) and using monetary values per QALY. The CBA case studies on vehicle safety improvements presented in Chapter 6 demonstrate that using a detailed injury classification and establishing a linkage with human body model simulations improve the accuracy of CBA and that standard CBA would under- or overestimate the benefits of non-fatal injury prevention considerably.

7.3. Conclusions and implications for policy making and further research

Based on the findings discussed in Section 7.2, this section presents the main conclusions of this thesis and their implications for policy making and further research.

1. ***Estimates the impact of road crashes on welfare (or social costs) show a wide variation across countries, which is mainly explained by methodological differences.***

The welfare impact of road crashes is estimated at the equivalent of 0.4 to 6.0% of GDP in different countries. Major methodological differences for estimating this impact were found between countries, particularly with respect to the valuation of human costs. The WTP-method results in much higher estimates of human costs than other methods. Consequently, the welfare impact of road crashes is found to be much higher in countries that apply the WTP-method. In addition, several differences in costs items included in assessments of the road crash costs contribute to the variation of the cost. Differences is road safety performance explain the cost differences between countries only to a very limited extent.

The implications of this conclusions are as follows:

- *Harmonization is needed for using social costs as an international policy making indicator.*
  The social costs of road crashes are regarded as a high-level indicator for road safety policy making (Bliss & Breene, 2009) and the costs are reported in road safety publications aimed at supporting decision making (WHO, 2015; ITF, 2017). However, the methodological differences identified in this thesis, and their impact on the costs, prevent using this indicator at the international level. Harmonization of methods is needed to be able to make sound international comparisons. Estimates of the costs of road crashes can be used at the national level, although limitations of the estimates and potential underestimation should be considered.
- *New international guidelines are needed for social cost calculations.*
  Developing new international guidelines for estimating the social costs of road crashes is recommended as a first to step to more harmonization. They should provide, among others, guidance on the cost items to be included and the methods to be applied to estimate each cost item. In addition, data availability is a challenging issue for road crash cost studies, as illustrated by the case study for Kazakhstan presented in Chapter 4. Therefore, new guidelines should also address the issue of data collection and strategies to cope with data gaps. The European COST313 project (Alfaro et al., 1994) was a first international initiative to harmonize road crash cost estimates. However, this thesis shows that there the road crash costing practices still differ considerably between countries (including European countries). Obviously, implementation of new guidelines in individual countries is needed to actually achieve more harmonization, which requires endorsement of new guidelines by national governments, research institutes and international organizations.

2. ***In many countries the welfare impact of road crashes is underestimated due to methodological shortcomings.***

The welfare impact of road crashes is underestimated for several reasons. Firstly, a WTP-based estimate of the human costs resulting from road crashes, which is an essential element of assessing the comprehensive welfare impact of road crashes, is missing in many countries. Other methods than the WTP-method are used instead, which implies that the welfare impact is underestimated in these countries. This applies to the low- and middle-income countries included in the review presented in this thesis, but also to about half of the high-income countries. Secondly, underreporting of crashes and casualties is not taken into account in the majority of the official road crash estimates, which further contributes to a considerable underestimation of the welfare impact. Thirdly, underestimation results from the fact that many countries do not include the costs of property damage only crashes, which account for a considerable proportion of the total road crash costs.

The implication of this conclusion for further research is to:

Improve the quality of future studies on social costs of road crashes by (1) including WTP-values, (2) address underreporting, (3) include the costs of property damage only crashes and (4) conduct sensitivity analysis.

To improve the quality of estimates of the welfare impact of road crashes, it is important to address the methodological shortcomings as identified in this thesis in future studies. Availability of international guidelines, as discussed above, can help to improve the methodologies as applied in individual countries. However, the three methodological issues mentioned above can be challenging, especially for LMIC. The main challenges and potential solutions are the following:

- Conducting a WTP-study is expensive and the required resources may not be available. Countries may conduct a joint WTP-study, as has been done in four European countries recently (Schoeters et al., 2022). This reduces the study costs and has the additional advantage of producing comparable monetary values (based on the same methodology) in different countries. Also, value transfer may be used as an alternative for a country-specific study (Freeman et al., 2014). This means that values from one or more countries are applied in ('transferred to') other countries, taking into account country differences such as income per capita. For example, a value transfer function that specifies the relation between the value of a statistical life (VSL), based on WTP, and GDP per capita is available (Milligan et al., 2014). This allows estimating the VSL without the need to conduct a WTP-study.
- The issue of underreporting is a well-known problem in road safety research in general. For example, GRSF (2020) reports that the underreporting rate of road fatalities is estimated at 11%, 51% and 84% in high-, middle- and low-income countries respectively, while the underreporting rate of non-fatal injuries is likely to be even higher. Improving data collection procedures and linking data from different sources, in particular police, hospitals and insurance data, is needed to reduce underreporting rates (Derriks and Mak, 2007; ITF, 2019), which is a prerequisite for improving the accuracy of estimates of the social costs of road crashes. Additionally, international evidence on underreporting rates (WHO, 2018; GRSF, 2020) can be used in cost studies to estimate the actual number of road casualties.
- Accurate data on PDO crashes is not available in most countries, since the number of fatalities and serious injuries are the main indicators used in road safety policy making (Van Wee et al., 2014). However, this thesis demonstrates that PDO crashes have a considerable impact on welfare. For future road crash studies, it is recommended to pay specific attention to the estimation of the number of PDO crashes and the costs of these crashes, for example by conducting surveys on people's involvement in PDO crashes and the associated costs (Taylor, 1990). Alternatively, evidence on the number of PDO crashes in other countries, for example relative to the number of injury crashes, can be used as a second-best option.
- It is recommended to conduct sensitivity analyses to address uncertainties in the input data which has rarely been done in studies on road crash costs. An exception is a recent study on the social costs of road crashes in Azerbaijan, where the influence of different assumptions on underreporting and the number of PDO crashes as well as different transfer functions for the VSL was assessed (World Bank, 2021).

3. *Road crashes impose a large welfare burden on society.*

Taking into account the methodological shortcomings and the resulting underestimation as discussed above, in most countries the welfare impact of road crashes is most likely at the higher end of the range found in this thesis (the equivalent of 0.4 to 6% of GDP) or even higher, particularly in LMIC. This is confirmed by the case study on the costs of road crashes in Kazakhstan presented in this thesis, where the costs were conservatively estimated at the equivalent of 3.3% of GDP. This implies that road crashes impose a large welfare burden on society, which is, for example, found to be 3 to 7 times larger than the welfare impact of traffic congestion in some countries (Cambridge Systematics, 2011; SWOV, 2022).

The implications of this conclusion are:

- *Large potential cost savings as an extra incentive for road safety investments.*
  The number of road fatalities and serious injuries are mostly used for setting road safety policy targets (Van Wee et al., 2014) and therefore road safety policy making concentrates on these indicators. However, reducing the social costs can be used as an additional argument to improve road safety and to justify road safety investments. The high socio-economic burden of road crashes implies that implementing effective road safety investments can yield large cost savings. Consequently, social cost-benefit analyses have demonstrated that the benefits of road safety measures often outweigh the costs (Winkelbauer and Stephan, 2005; CEDR, 2008; Daniels et al., 2019). Policy makers can use this information to select the most cost-beneficial road safety measures and justify their choices on spending budgets on road safety improvements.
- *Insight in the socio-economic impact of road crashes can be enlarged by further research on impact on the economy, on stakeholders and distributional impacts.*
  The large welfare burden of road crashes found in this thesis was based on a welfare economic approach. However, future studies may adopt other perspectives which could be relevant for policy making as well. For example, policy makers may be interested in the impact of road crashes on the economy as measured by, for example, GDP per capita. Although this a narrower approach of welfare, GDP per capita is a widely used policy making indicator and therefore the influence of road crashes on this indicator is interesting and relevant. Recent studies have attempted to assess this impact at the global level (Chen et al., 2019) and in a few low- and middle-income countries (World Bank, 2017). However, detailed country-specific studies on the impact of road crashes on the economy are not available.
  Also, the perspective of individual stakeholders could be interesting. Future studies could concentrate on the question who is bearing the socio-economic burden of road crashes. Insight in this distribution of the costs among stakeholders, such as road casualties, insurance companies, employers and governments, can help identifying (financial) incentives for them, or lack of these motivations, to improve road safety. For example, in a Dutch study the costs of road crashes for municipalities, and thus the potential gains of road safety improvements for them, were assessed (Wijnen, 2015).
  Distributional impacts are also an interesting addition to the welfare economic approach as applied in CBA. For example, decision makers may want to consider safety impacts on different groups of road users, such as car drivers versus vulnerable road users or youth versus elderly. Another example is a trade-off between preventing a small number of road casualties and a (small) travel time saving for a large number of road users. The welfare

economic approach and its focus on individual preferences may not (fully) meet the information needs of decision makers in these cases. Mouter et al. (2017) introduced the concept of the WTP as a citizen, as opposed to the conventional WTP as a consumer, which could help to address these issues. Further research in this area is recommended.

4. ***Non-fatal injuries account for a major proportion of the welfare impact of road crashes, but insufficient attention is paid to them in economic assessment of road safety.***

Current knowledge on the social costs of road crashes indicates that non-fatal injuries account for a major proportion of the welfare impact of road crashes. This impact is generally about twice as large as the welfare impact of fatalities. The large number of non-fatal injuries, as compared to the number of fatalities, contributes to this high welfare impact. Despite the importance of non-fatal injuries from a welfare perspective, the number of studies on monetary valuation of preventing non-fatal injuries is very limited, especially as compared to the abundance of literature on the monetary valuation of preventing fatalities. Moreover, the prevention of non-fatal injuries is included only on a highly aggregated level in cost-benefit analysis, without considering the specific type of injury and impacts on injury severity. This results in inaccurate results of CBA of road safety measures aimed at preventing specific injury types or at reducing injury severity, such as several vehicle safety systems.

The implications of this conclusion are:

- *The high welfare burden justifies mores policy making attention for non-fatal injuries.*
  Non-fatal injuries have gained more attention in road safety policy making in recent years. For example, a quantitative European target for reducing the number of non-fatal road injuries was added to the target for preventing fatalities (MaltaEU, 2017). This increasing attention for non-fatal injuries is justified by the welfare impact of non-fatal injuries since this impact is much larger than the welfare impact of fatalities. Consequently, the potential social benefits of preventing non-fatal injuries are also larger as compared to preventing fatalities. WHO (2018) reports that 62% of the countries participating in their survey have set a target for reducing the number of fatalities, but the number of countries having a target for preventing non-fatal injuries is unknown. Given the importance of non-fatal injuries and their impact on welfare, setting national targets for reducing non-fatal injuries is recommended.
- *More monetary valuation studies on non-fatal injuries are needed.*
  The discrepancy between the potential magnitude of the welfare impact of non-fatal road injuries and the attention paid to it in the literature justifies more research on the welfare assessment of preventing non-fatal injuries. Conducting more studies on monetary valuation of preventing non-fatal injuries is recommended, since the number of such studies is very limited and the resulting values vary widely. Preferably a combination of stated choice and QALYs is used, as this was found to be the most promising methodological approach in this thesis. Increasing the number of valuation studies will help to provide better guidance on values to be used in calculations of the social costs of road crashes and CBA, since current recommended values do not have a solid basis in the literature (as discussed in Chapter 5).

- *More detailed assessment of non-fatal injuries is recommended for cost-benefit analysis*
  For future CBAs of road safety measures aimed at preventing specific injury types or at reducing injury severity, it is recommended to apply the novel methodology presented in this thesis with a detailed classification of non-fatal injuries. Several areas of further improvement of the methodology were identified. This concerns in particular the impact of injury severity reduction on quality of life, for which injury disability weights need to be disaggregated into severity categories. Furthermore, limited availability of detailed crash risk data was identified as a challenge for case studies. Future applications could address this issue by exploring more data sources, such as insurance data.

7.4. A reflection on this thesis: some strengths and limitations

This thesis is about the impact of road crashes on welfare, as well as on how to estimate the welfare impact of measures aimed at improving road safety. To assess the negative impact of road crashes on welfare, or the social costs of road crashes, a literature review and an expert survey on costs estimates in individual countries were presented in chapters 2 and 3. The strength of this approach is that it allows to collect data from a relatively large number of countries and to give a comprehensive overview of the costs of road crashes around the world. The appropriateness of the methods used in these cost studies was assessed, but other quality aspects of the cost estimates, such as the quality of the input data, was beyond the scope of the research. This is a potential weakness, because the robustness of the results presented in chapters 2 and 3 depends on the (mostly unknown) quality of the cost data that were collected in the original studies. On the other hand, this is mitigated to some extent by the fact that most of the cost estimates are officially used by national governments, which are likely apply quality criteria to the research results that they are using.

Furthermore, it should be noted that the worldwide analysis of road crash costs was conducted several years ago (2013-2014). A more recent review (Bougna et al., 2022) shows that new road crash cost studies have been conducted in some countries since then, which implies that some results of this chapter may be outdated. However, a main finding is that the costs of road crashes show wide variation across countries (the equivalent of 0.4 to 6.0% of GDP). This result is confirmed by Bougna et al., who found an even wider range (0.3% to 6.7% of GDP). Note that the review by Bougna et al. does not assess the costs of road crashes in detail. Consequently, chapters 2 and 3 still present the most recent analyses of cost estimates in individual countries that include an assessment of the included costs items, the methods used to estimate each cost item and the size of the costs with breakdowns into cost items and injury severity levels. Obviously, it would still be interesting to update this work in the future by including more recent studies.

To get a better understanding of the costs of road crashes in LMIC, the social costs of road crashes were further assessed by a case study in Kazakhstan, where the costs were conservatively estimated at the equivalent of 3.3% of GDP. The strength of this case study is the fact that, in contrast with most other studies in LMIC, a combination of methods is applied, including a WTP-method. This allows to capture all relevant costs from a broad welfare perspective. Clearly, case studies in more countries would be needed to draw more general conclusions on the size of the costs of road crashes in LMIC. Nevertheless, it is to be expected that the relatively high road injury risk in many LMIC, like in Kazakhstan, will contribute to relatively high costs in these countries.

Chapters 5 and 6 concentrated on including non-fatal injuries in economic analysis of road safety. These chapters represent a first attempt to the bridge the gap between the lack of attention given to non-fatal road injuries in economic studies and their importance for road safety policy making. These chapters mainly take a methodological point of view, which implies that the relevance for policy making is limited on the short term. Chapter 5 presented a review of the literature on monetary valuation of preventing non-fatal road injuries, which had not been done before in the literature. It demonstrated that the number of studies is very limited and that the values per injury show wide variations. Unfortunately, this provides little guidance for values to be used in policy evaluation. Conducting more valuation studies in the future is needed, drawing on the methodological recommendations formulated in Chapter 5. The applicability of the CBA-method presented in Chapter 6 is still limited because several of the required inputs, such as crash risk data and injury risk curves, are not always available. More research and data collection are needed to pave the way for applying the method to more road safety measures. Clearly, such conclusions and the limited practical applicability on the short term are inevitable when conducting research on topics which are relatively new in the literature, such as economic assessment of preventing non-fatal injuries. Nevertheless, the studies presented in this thesis can be considered as a first step to integrate non-fatal injuries accurately in economic assessment of road safety and to assist policy makers making choices on road safety interventions and preventing non-fatal injuries.

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Summary: Road safety and welfare

Road crashes and economic assessment

Road crashes are a worldwide societal problem and they have a negative impact on welfare. This is reflected by several types of social costs that result from road crashes, including medical costs, loss of human productive capacities and damage to vehicle and other properties, as well as intangible impacts (‘human costs', loss of quality of life and life years). Understanding the impact of road crashes on welfare is important for evidence-based road safety policy making. Information on this impact is used to emphasize the need to improve road safety from a socio-economic point of view and the social costs of road crashes are used as an indicator for road safety performance. Improving road safety and reducing the negative impact of road crashes on welfare requires efficient spending of the available resources. Economic assessment methods, in particular social cost-benefit analysis (CBA), can help decision makers prioritizing different investment options and allocating resources efficiently within the field of road safety or across several policy areas.

Aim of this thesis, research questions and methods

This thesis is aimed at critically assessing the literature and current practices for estimating the impact of road crashes and road safety measures on welfare and at improving and applying methods for estimating these impacts. Four research questions are addressed in this thesis, based on gaps in the literature as identified in a brief literature overview presented in Chapter 1. This shows that there is no recent systematic and detailed overview of the social costs of road crashes as estimated in individual countries and the methodologies used to estimate these costs. Moreover, the number of studies on the costs of road crashes in low- and middle-income countries is limited and they have methodological shortcomings. Furthermore, relatively little attention is paid to non-fatal injuries in economic assessment in the field of road safety. The number of studies on monetary valuation of preventing non-fatal injuries is very limited and cost-benefit analyses include the prevention of non-fatal injuries only on a highly aggregated level.

The research questions, methods, related literature gaps and thesis chapters addressing each question are presented in Table S.1.

A combination of different methods is used, in particular literature reviews on the social costs of road crashes and monetary valuation of preventing non-fatal injuries, a survey among experts on road crash costs in European countries, a case study on the social costs of road crashes in middle-income country (Kazakhstan) and the development of a CBA-methodology with novel elements with respect to non-fatal injury prevention (see Table S.1).

Welfare economic theory and the (related) theory of social cost-benefit analysis is used to define the welfare impacts of road crashes. Following these theories, a broad definition of welfare is adopted in this thesis, which implies (among others) that intangible impacts of road crashes, such as impacts on quality of life and longevity, are included.

Table S.1: Research questions, methods, related gaps in the literature and thesis chapters addressing each research question.

Research question	**Method**	**Literature gap**	**Thesis chapter**
1. Which methodologies are applied in individual countries to assess the welfare impact (or social-economic costs) of road crashes?	(a) Literature review of road crash costs estimates worldwide (b) Analysis of official road crash costs estimates in European countries, based on a survey	There is no recent and systematic overview of the social costs of road crashes in individual countries and methodologies used	2 (a) 3 (b)
2. What is the size of this impact in individual countries and what is the breakdown of this impact into injury severity categories and cost elements?			
	Case study on road crash costs in Kazakhstan	Number of studies on social costs of road crashes in LMIC is very limited ad they have methodological shortcomings	4
3. What is/are the most appropriate method(s) to estimate the economic value of preventing road injuries?	Literature review and critical assessment of appropriateness of WTP methods for reducing non-fatal risks	There is no critical and systematic discussion of WTP methods for reducing non-fatal road crash risk and no guidance on most appropriate method	5
4. How can the estimation of the benefits of preventing non-fatal injuries in CBA be made more accurate and take into account impacts on specific types of injuries and injury severity?	Development of a CBA-methodology with novel elements, including a detailed classification of injury types and linkage to human body models; application in three case studies	The calculation of the benefits of preventing non-fatal injuries in CBA does not take into account injury type or injury severity at sufficient detail, and a methodology does not exist.	6

Social costs of road crashes worldwide

Chapter 2 presents a literature review on the social costs of road crashes as estimated in individual countries worldwide. It gives a detailed overview of road crash cost studies, discusses the methodologies used in these studies and summarizes the results of the studies in terms of the size of the costs and breakdowns of the cost into injury or crash severity and cost elements. The analysis is based on publications about the national costs of road crashes of 17 countries, of which ten high income countries (HICs) and seven low- and middle-income countries (LMICs). The analysis shows that the social costs of road crashes in HICs are estimated at the equivalent of 0.5% to 6.0% of their gross domestic product (GDP) with an average of 2.7%. Excluding countries that do not use the generally recommended willingness to pay (WTP) approach and countries that do not correct for underreporting, the average costs are the equivalent of 3.3% of GDP. For LMICs that do correct for underreporting the proportion of GDP ranges from 1.1% to 2.9%. However, none of the LMICs included has included WTP-values.

A major part of the costs is found to be related to non-fatal injuries: an average share of 50% for both HICs and LMICs. The average share of fatalities in the costs is about 23% and 30% in HICs and LMICs respectively, and the remainder of the costs is related to property damage only (PDO) crashes.

The analysis demonstrates that there are methodological differences between countries, which partly explain the differences in the estimated costs. Countries may or may not correct for underreporting of road crashes and casualties, they may or may not use the WTP-approach and there are differences regarding the included cost elements and methods used for estimating each cost element.

Official estimates of the social costs of road crashes in Europe

In Chapter 3, an analysis is made of the official road crash cost estimates in 31 European countries, as used by governmental organizations in economic assessment of road safety or broader transport projects, based on the survey among experts from each country. The total costs of road crashes are found to be equivalent to 0.4–4.1% of GDP. On average the share of serious injuries in the total road crash costs is 2.4 times higher than the share of fatalities. However, the distribution of the costs among severity categories varies considerably between countries, which is likely to be partly explained by differences in crash reporting rates at each severity level. Furthermore, a large proportion of the countries (44%) does not include PDO crashes, which implies an important underestimation of the total costs.

Wide ranges of monetary values of preventing a road casualty are found. The value of preventing a fatality varies from 0.7 to 3.0 million Euro (2015 prices). The value of preventing a serious injury ranges from 2.5% to 34.0% of the value per fatality and the value of preventing a slight injury from 0.03% to 4.2% of the value of a fatality. Human costs make up a large part of the costs per casualty if based on WTP: 54-94% of the costs of a fatality and 51-91% of the costs of a serious injury in European countries.

The method used for obtaining values has a major impact on the values. Most countries apply the WTP approach, which gives higher values than other methods. The human costs per fatality are much higher (€1.2 million and higher, 2015 prices) if based on WTP than values based on other methods (less than €0.1 million except one value of 0.6 million, 2015 prices). Additional explanations for variations in the values include differences in the cost components that are taken into account and different definitions of a serious and a slight injury.

Case study on the social costs of road crashes in Kazakhstan

Chapter 4 presents a case study on the social costs of road crashes in Kazakhstan. Five costs components are considered: medical costs, production loss, human costs, vehicle damage and administrative costs. A hybrid methodological approach is used, which implies that different types of methods, three in this case, are applied to capture all costs: the human capital method (production loss), WTP method (human costs) and restitution costs method (medical costs, vehicle damage and administrative costs). Input data were retrieved from existing databases from a variety of road safety stakeholders and other organizations. A household survey was conducted to collect additional information, including data on medical treatment, car damage and police attendance at the crash location. To estimate human costs, the survey also included questions on people´s willingness to pay for fatal risk reductions. A contingent valuation questionnaire design was used with two choice scenarios: a choice between two routes and between two cities, both with different fatal road crash risks. Remaining data gaps are bridged by using data from other countries.

In this case study, the social costs of road crashes in Kazakhstan are estimated at 6.8 billion USD in 2012, which is the equivalent of 3.3% of GDP. This should be considered as a lower limit, because conservative estimates of the number of road casualties were used. Human costs account for 81% of the total costs, vehicle damage for 11% and production loss for 6%. Administrative and medical costs are relatively very small cost components. More than half of the costs is related to non-fatal injuries, while fatalities account for about a third of the total costs and property damage for approximately 10%. The costs of a fatality are estimated at 764,000 USD, the costs of a serious and slight injury at 101,000 USD and 8,000 USD respectively and the costs of a PDO crash at 12,000 USD (2012 prices).

The case study indicates that the costs of road crashes in LMICs are likely to be at the higher end of the range of costs estimates (expressed as a percentage of GDP) found in chapters 2 and 3, if all major cost components are included and estimated using the most appropriate valuation methods. This is related to the relatively high number of road casualties in these countries, as indicated by high road mortality rates.

Monetary valuation of preventing non-fatal injuries

In Chapter 5, WTP-methods for monetary valuation of preventing non-fatal road injuries are reviewed and critically assessed. Based on a literature review, eight different WTP-methods for monetary valuation of preventing non-fatal road injuries are identified. They are classified into three groups: direct WTP-methods, indirect WTP-methods and the QALY-method (Quality Adjusted Life Year). Direct WTP-methods obtain the WTP for reducing the risk of getting injured in a road crash in a direct way using stated or revealed preference methods, while indirect methods determine the WTP for reducing non-fatal risks relative to the WTP for a fatal risk reduction. The QALY-method uses estimates of loss of quality of life and the monetary value of a QALY.

The appropriateness of WTP-methods is assessed using five criteria: theoretical basis, reliability, ability to handle injury diversity, practicality and ethical issues. Based on these criteria, stated choice (SC), a direct WTP-method, is found to be the preferred method. In SC surveys, respondents are asked to make choices between several situations (mostly travel routes), which are different with respect to safety, costs and other attributes such as travel time. SC is rooted in random utility theory and has a stronger theorical basis than most other methods. Due to its focus on trade-offs that individuals make, SC is less prone to several types of bias (for example related to the survey design) than other stated preference methods. Moreover, SC is less associated with ethical concerns, because it uses data on choices people make in real life instead of asking people in a more direct way how much they are willing to pay for preventing injuries. As compared to revealed preference methods, SC (like other stated preference methods) has the practical advantage of not being dependent on the availability of data on actual behaviour.

A main limitation of SC is the fact that only a few types of injuries can be assessed and monetized. The QALY-method is the only method which is capable of deriving monetary values of a large range of injury types and severities. Combining SC and QALYs can be a promising direction for future research. By combining SC and the QALY-method, the strengths of both approaches are merged and this combined approach could produce detailed monetary values of preventing non-fatal injuries with a strong theoretical basis.

The number of WTP-studies on monetary valuation of preventing non-fatal road injuries is small: only 13 studies were found and included in the review. Although the range of values of a prevented serious injury found in these studies is very wide, 1% to 48% of the value of a statistical life, the literature indicates that preventing serious road injuries is at least as relevant as preventing fatalities from a social welfare point of view.

Non-fatal injuries in cost-benefit analysis of road safety measures

Chapter 6 presents a methodology for including the benefits of preventing non-fatal injuries in CBA. The methodology includes two novel elements as compared to the standard CBA-methodology in the field of road safety. Standard CBA includes non-fatal injuries on a highly aggregated level, which distinguishes (at most) only between serious and slight injuries without specifying the injury type. The first new element is a detailed classification of injury types and injury severity, based on the EUROCOST injury classification of 39 injury groups and the Abbreviated Injury Scale (AIS). The injury (severity) reduction is translated into quality of life gains (Quality Adjusted Life Years, QALYs) and monetary benefits using a monetary value per QALY. Secondly, a linkage with human body model (HBM) simulations is established. Simulations of the impacts of a collision on the human body and the resulting injury probability changes are applied to determine the safety benefits. Integrating HBM results in CBA is shown to be an efficient way to obtain the required detailed information on the impacts of safety interventions for which field data are not (yet) available.

The methodology is applied to three case studies: an active headrest aimed at reducing whiplash associated disorders, autonomous emergency braking systems aimed at preventing collision of cars and pedestrians and cyclists, and an improved tram front aimed at reducing injury severity of tram-pedestrian collisions. Standardized data, including injury disability weights (reflecting impact on quality of life), proportion of injuries resulting in lifelong health consequences and monetary values, among others, are used to translate the output from HBMs into QALYs and monetary benefits. The case studies illustrate the added value of the methodology in terms of a more detailed and accurate assessment of the specific safety benefits of vehicle safety systems. They demonstrate that the standard CBA approach would under- or overestimate the benefits of non-fatal injury prevention considerably. Furthermore, the case studies show that limited availability of case-specific data on crash risks and costs of safety systems is as a main challenge for cost-benefit analysis of vehicle safety systems.

Findings on the research questions

Chapter 7 presents answers on the research questions addressed in this thesis. In addition, conclusions and recommendations for policy making and research in the field of road safety are formulated in this chapter.

1. Which methodologies are applied in individual countries to assess the welfare impact (or social-economic costs) of road crashes?

Three main valuation methodologies are available in the literature to estimate the social costs of road crashes: the restitution costs method, human capital method and willingness to pay (WTP) method. They are aimed at economic valuation of different welfare impact and therefore a combination of the three methods is needed to capture all social costs. The restitution costs method is generally applied to calculate medical costs, property damage, and administrative costs while the human capital method is used to calculate production loss. However, a majority of the countries does not adopt the WTP method. This is an important omission in road crash cost estimates in these countries, which results in a substantial underestimation of the costs.

No large differences between countries were found with respect to the main cost components included in cost studies, but differences were found at a more detailed level (within the main components). Avoidance costs, which result from adapting travel behaviour because of (perceived) safety levels, is an important missing cost item in road crash cost assessments.

2. What is the size of this welfare impact in individual countries and what is the breakdown of this impact into injury severity and cost elements?

The welfare impact of road crashes (or the social costs of road crashes) is estimated at the equivalent of 0.4 to 6.0% of gross domestic product (GDP) in individual countries. The large variation across countries is mainly explained by the differences in the methodologies used to estimate the costs, particularly whether or not WTP-values are included. The case study in Kazakhstan, where the costs were conservatively estimated at the equivalent of 3.3 of GDP, suggests that the costs of road crashes in LMICs are likely to be at the higher end of the range, given the relatively high number of road casualties in many of these countries and the fact that the costs are likely to be underestimated due to conservative assumptions.

Non-fatal injuries have a major share in the social costs of road crashes, on average around 50% of the total costs, although the distribution of the costs among severity categories varies considerably between countries. The costs of non-fatal injuries are (much) larger than the costs of fatalities and PDO crashes. Human costs have a major share in the total costs of road crashes, typically more than 50% of the total costs, especially if they are based on the WTP-method. Other relatively large cost components are property damage and production loss. Medical costs and administrative costs are relatively small.

3. What is/are the most appropriate method(s) to estimate the monetary value of preventing non-fatal road injuries?

Based on the assessment of eight WTP-methods, stated choice (SC) is found to be the preferred method for monetary valuation of preventing non-fatal road injuries, particularly because of the theoretical basis and reliability. A main limitation of this method is the fact that SC can include only a few types of injuries. Only the QALY (Quality Adjusted Life Years) method is capable of deriving monetary values of a large range of injury types and severities. Therefore, combining SC and the QALY-method is a promising direction for future research.

To calculate medical costs and production loss resulting from road injuries, the most suitable methods are the restitution costs and human capital method respectively (see above). These methods are generally applied and they are relatively undebated.

4. How can the estimation of the benefits of preventing non-fatal injuries in cost-benefit analysis (CBA) be made more accurate and take into account impacts on specific types of injuries and injury severity?

A detailed injury classification and injury severity categories, such as the EUROCOST injury classification and the AIS as applied in this thesis, in combination with QALYs can be used to estimate the monetary benefits of preventing non-fatal injuries more precisely. Results of HBM simulations are a useful source for data on the impacts of road safety measures on specific injuries and on their severity, which are needed for this disaggregated approach. Since standard CBA does not take into account injury type and severity (other than slight versus serious injuries), this novel approach improves the accuracy of CBA of road safety measures considerably, particularly if they (such as several vehicle safety systems) are aimed at preventing specific types of injuries or at injury severity reduction.

Conclusions and their implications for policy making and further research

1. *Estimates of the impact of road crashes on welfare show a wide variation across countries, which is mainly explained by methodological differences.*

The main methodological difference is whether or not a WTP-method is applied to estimate human costs. This has a considerable impact on the estimated social costs, since WTP-values are much higher than values based on other methods. Furthermore, there are differences with respect to the costs items included in studies on the welfare impact of road crashes.

This conclusion implies that international harmonization of methods is needed for using the social costs as an international policy making indicator. Developing new international guidelines for estimating the social costs of road crashes is recommended as a first to step towards harmonization. They should provide guidance on, among others, the cost items to be included and the methods to be applied to estimate each cost item.

2. *In many countries the welfare impact of road crashes is underestimated due to methodological shortcomings.*

The welfare impact of road crashes is underestimated because WTP-values are not included, underreporting of the number of casualties and crashes is not (properly) considered and/or an estimate of the costs PDO crashes is missing. It is recommended to address these issues by:

- conducting WTP-studies in more countries or using WTP-values from other countries (‘value transfer’);
- increase the quality and representativeness of road safety statistics by improving road crash and casualty data collection procedures and linking data from different sources, and/or using international research findings on underreporting rates in cost studies;
- include estimates of the costs of PDO crashes in cost studies, for example by conducting surveys on people’s involvement in PDO crashes and the associated costs, or use evidence on these costs from other countries;
- include sensitivity analyses in cost studies to address uncertainties in the input data.

3. *Road crashes impose a large welfare burden on society.*

In most countries, particularly LMIC, the welfare impact of road crashes is most likely at the higher end of the range found in this thesis (the equivalent of 0.4 to 6.0% of GDP) or even higher, given the methodological shortcomings and the resulting underestimation of costs. This is confirmed by the case study in Kazakhstan, where welfare impact is conservatively estimated at the equivalent of 3.3% of GDP.

This conclusion implies that implementing effective road safety investments can yield large cost savings, which can provide policy makers an extra incentive to invest in improving road safety. Insight in the societal and economic impact of road crashes can be enlarged by adopting other perspectives in future research. This may include the impact on the economy, as measured by (for example) GDP per capita, and the distribution of the costs among stakeholders. Including distributional impacts in CBA, for example a small increase in the number of road casualties versus a (small) travel time saving for a large number of road users, is also recommended for future research.

4. *Non-fatal injuries constitute a major portion of the overall welfare impact of road crashes, yet they often receive insufficient attention in economic assessments of road safety.*

The number of studies on monetary valuation of preventing non-fatal injuries is very limited, although the welfare impact of non-fatal injuries is much larger than that of fatalities. Furthermore, non-fatal injuries are included only on a highly aggregated level in CBA, without properly taking into account the specific type of injury and impacts on injury severity.

The high welfare burden justifies mores policy making attention for non-fatal injuries, for example by setting national targets for reducing the number of non-fatal injuries in more countries. Furthermore, it is recommended to conduct more studies on monetary valuation of preventing non-fatal injuries, preferably using a combination of the stated choice method and QALYs. This will help to provide better guidance on values to be used in calculations of the social costs of road crashes and in CBA.

It is recommended to further develop and apply the novel CBA-methodology with the detailed classification of non-fatal injuries as presented this thesis. Areas of improvement include further analysis of the impact of injury severity reduction on quality of life (using disability weights) and improving crash risk estimates, for example by using insurance statistics.

Samenvatting: Verkeersveiligheid en welvaart

Verkeersongevallen en economische analyse

Verkeersongevallen vormen een wereldwijd maatschappelijk probleem en beïnvloeden de welvaart negatief. Dit komt tot uiting in verschillende soorten maatschappelijke kosten die het gevolg zijn van verkeersongevallen, waaronder medische kosten, verlies van menselijke productiecapaciteit en schade aan voertuigen en andere eigendommen, maar ook in immateriële gevolgen ('human costs', verlies van levenskwaliteit en levensjaren). Inzicht in het effect van verkeersongevallen op de welvaart is belangrijk voor empirisch onderbouwde beleidsvorming inzake verkeersveiligheid. Informatie over dit effect wordt gebruikt om de noodzaak van verbeteringen in verkeersveiligheid vanuit maatschappelijk oogpunt te benadrukken, en de maatschappelijke kosten van verkeersongevallen worden gebruikt als prestatie-indicator voor verkeersveiligheid. Om de verkeersveiligheid te verbeteren en de negatieve invloed van verkeersongevallen op de welvaart te verminderen, moeten de beschikbare middelen efficiënt worden besteed. Economische evaluatiemethoden, met name de maatschappelijke kosten-batenanalyse (KBA), kunnen besluitvormers helpen bij het prioriteren van verschillende investeringsopties en bij het efficiënt toewijzen van middelen op het gebied van verkeersveiligheid of op andere beleidsterreinen.

Doel van dit proefschrift, onderzoeksvragen en methoden

Dit proefschrift is gericht op het kritisch beoordelen van de literatuur en de huidige praktijk voor het bepalen van de effecten van verkeersongevallen en verkeersveiligheidsmaatregelen op de welvaart, en op het verbeteren en toepassen van methoden voor het bepalen van deze effecten. In dit proefschrift worden vier onderzoeksvragen behandeld, gebaseerd op hiaten in de literatuur zoals vastgesteld in het beknopte literatuuroverzicht in Hoofdstuk 1. Hieruit blijkt dat er geen recent systematisch en gedetailleerd overzicht bestaat van de geschatte maatschappelijke kosten van verkeersongevallen in individuele landen en van de methoden die wordt gebruikt voor deze kostenschattingen. Bovendien is het aantal onderzoeken naar de kosten van verkeersongevallen in lage- en middeninkomenslanden beperkt en vertonen deze onderzoeken methodologische tekortkomingen. Daarnaast wordt er bij economische verkeersveiligheidsanalyses relatief weinig aandacht besteed aan verkeersgewonden. Het aantal onderzoeken naar de monetaire waardering van de preventie van verkeersgewonden is zeer beperkt en kosten-batenanalyses nemen de preventie van verkeersgewonden alleen op een sterk geaggregeerd niveau mee.

De onderzoeksvragen, methoden, de bijbehorende hiaten in literatuur en de hoofdstukken van het proefschrift die deze vragen behandelen, staan in tabel S.1.

Er is een combinatie van verschillende methoden gebruikt, met name literatuuronderzoek naar de maatschappelijke kosten van verkeersongevallen en de monetaire waardering van de preventie van verkeersgewonden, een enquête onder deskundigen over de kosten van verkeersongevallen in Europese landen, een casestudy naar de maatschappelijke kosten van verkeersongevallen in een land met een middeninkomen (Kazachstan) en de ontwikkeling van een KBA-methodiek met nieuwe elementen wat betreft de preventie van verkeersgewonden (zie tabel S.1).

De theorie van de welvaartseconomie en de (verwante) theorie van maatschappelijke kosten-batenanalyse worden gebruikt om de welvaartseffecten van verkeersongevallen te definiëren. In navolging van deze theorieën wordt in dit proefschrift een brede definitie van welvaart gehanteerd, wat (onder andere) inhoudt dat ook immateriële effecten van verkeersongevallen, zoals effecten op de kwaliteit van leven en levensduur, worden meegenomen.

Tabel S1: Onderzoeksvragen, methoden, bijbehorende hiaten in de literatuur en de hoofdstukken die de onderzoeksvragen behandelen.

Onderzoeksvraag	**Methode**	**Hiaten literatuur**	**Hoofdstuk**
1. Welke methoden worden in afzonderlijke landen toegepast om de welvaartseffecten (of maatschappelijke kosten) van verkeersongevallen te bepalen?	(a) Literatuur review van kostenramingen van verkeersongevallen wereldwijd (b) Analyse van officiële kostenramingen van verkeersongevallen in Europese landen op basis van een enquête	Er is geen recent en systematisch overzicht van de maatschappelijke kosten van verkeersongevallen in individuele landen en de gebruikte methoden.	2 (a) 3 (b)
2. Hoe groot zijn de welvaartseffecten in afzonderlijke landen en wat is de uitsplitsing ervan in categorieën van letselernst en kostenposten?	Casestudy over de kosten van verkeersongevallen in Kazachstan	Het aantal studies naar de maatschappelijke kosten van verkeersongevallen in LMIC's is zeer beperkt en ze vertonen methodologische tekortkomingen.	4
3. Wat is/zijn de meest geschikte methode(s) om de economische waarde van het voorkomen van verkeersgewonden te schatten?	Literatuur review en kritische beoordeling van de geschiktheid van WTP-methoden voor reductie van het risico op niet-dodelijk letsel	Er is geen kritische en systematische bespreking van WTP-methoden voor reductie van het risico op niet-dodelijk letsel en geen leidraad voor de meest geschikte methode.	5
4. Hoe kan de schatting van de baten van het voorkomen van verkeersgewonden in KBA's nauwkeuriger worden gemaakt en rekening houden met effecten op specifieke soorten letsel en letselernst?	Ontwikkeling van een KBA-methodologie met nieuwe elementen, waaronder een gedetailleerde classificatie van soorten letsel gekoppeld aan 'human body models'; toepassing in drie casestudies	De berekening van de baten van het voorkomen van verkeersgewonden in KBA houdt onvoldoende rekening met het letseltype of de letselernst en er bestaat geen methodiek daarvoor.	6

Maatschappelijke kosten van verkeersongevallen wereldwijd

Hoofdstuk 2 bevat een review van de literatuur over maatschappelijke kosten van verkeersongevallen zoals geschat in individuele landen wereldwijd. Het geeft een gedetailleerd overzicht van onderzoeken naar de kosten van verkeersongevallen, bespreekt de methoden die in deze onderzoeken worden gebruikt en vat de resultaten samen met betrekking tot hoogte van de kosten en de uitsplitsing van de kosten naar letsel- of ongevalsernst en kostenposten. De analyse is gebaseerd op publicaties over de nationale kosten van verkeersongevallen van 17 landen, waarvan tien hoge-inkomenslanden (HIC's) en zeven lage- en middeninkomenslanden (LMIC's). Uit de analyse blijkt dat de maatschappelijke kosten van verkeersongevallen in HIC's worden geschat op het equivalent van 0,5% tot 6,0% van hun bruto binnenlands product (BBP), met een gemiddelde van 2,7%. Exclusief landen die geen gebruik maken van de algemeen aanbevolen ´willingness to pay´ (WTP) methode en landen die niet corrigeren voor onderregistratie, zijn de gemiddelde kosten gelijk aan 3,3% van het BBP. Voor LMIC's die corrigeren voor onderregistratie varieert het aandeel in het BBP van 1,1% tot 2,9%. Geen van de onderzochte LMIC's heeft echter WTP-waarden meegenomen.

Een groot deel van de kosten blijkt verband te houden met verkeersgewonden: een aandeel van gemiddeld 50% voor zowel HIC's als LMIC's. Het aandeel van verkeersdoden in de kosten is gemiddeld ongeveer 23% en 30% in respectievelijk HIC's en LMIC's, en de rest van de kosten is gerelateerd aan ongevallen met uitsluitend materiële schade (UMS).

De analyse toont aan dat er methodologische verschillen zijn tussen landen, die deels de verschillen in de geschatte kosten verklaren. Landen corrigeren al dan niet voor onderregistratie van verkeersongevallen en verkeersslachtoffers, ze gebruiken al dan niet de WTP-benadering en er zijn verschillen met betrekking tot de kostenposten die worden meegenomen en de methoden die worden gebruikt voor het schatten van elke kostenpost.

Officiële schattingen van de maatschappelijke kosten van verkeersongevallen in Europa

In hoofdstuk 3 wordt een analyse gemaakt van de officiële schattingen van de kosten van verkeersongevallen in 31 Europese landen, zoals gebruikt door overheidsorganisaties bij economische evaluatie van verkeersveiligheids- of bredere vervoersprojecten, gebaseerd op een enquête onder deskundigen uit elk land. De totale kosten van verkeersongevallen blijken gelijk te zijn aan 0,4-4,1% van het BBP. Gemiddeld is het aandeel van ernstig verkeersgewonden in de totale kosten van verkeersongevallen 2,4 keer hoger dan het aandeel van verkeersdoden. De verdeling van de kosten over de categorieën van letselernst verschilt echter aanzienlijk tussen landen, wat waarschijnlijk gedeeltelijk kan worden verklaard door verschillen in de registratiegraad van ongevallen op elk niveau van letselernst. Bovendien houdt een groot deel van de landen (44%) geen rekening met UMS-ongevallen, wat een belangrijke onderschatting van de totale kosten tot gevolg heeft.

De monetaire waarde van het voorkomen van een verkeersslachtoffer varieert sterk. De waarde van het voorkomen van een verkeersdode varieert van 0,7 tot 3,0 miljoen euro (prijspeil 2015). De monetaire waarde van het voorkomen van een ernstig verkeersgewonde varieert van 2,5% tot 34,0% van de waarde per verkeersdode en de waarde van het voorkomen van een licht gewonde van 0,03% tot 4,2% van de waarde van een verkeersdode. Immateriële kosten maken een groot deel uit van de kosten per slachtoffer indien gebaseerd op WTP: 54-94% van de kosten van een verkeersdode en 51-91% van de kosten van een ernstig gewonde in Europese landen.

De methode die wordt gebruikt voor waardebepalingen heeft een grote invloed op de waardes. De meeste landen passen de WTP-benadering toe, die hogere waardes oplevert dan andere methoden. De immateriële kosten per dode zijn veel hoger (1,2 miljoen euro en hoger, prijspeil 2015) als ze gebaseerd zijn op WTP dan waarden op basis van andere methoden (minder dan 0,1 miljoen euro, met uitzondering van één waarde van 0,6 miljoen euro, prijspeil 2015). Aanvullende verklaringen voor variaties in de waardes zijn onder andere verschillen in de kostenposten die worden meegenomen en verschillende definities van ernstig en licht gewonden.

Casestudy over de maatschappelijke kosten van verkeersongevallen in Kazachstan

Hoofdstuk 4 bespreekt een casestudy over de maatschappelijke kosten van verkeersongevallen in Kazachstan. Vijf kostencomponenten worden meegenomen: medische kosten, productieverlies, immateriële kosten, voertuigschade en administratieve kosten. Er wordt een hybride methodologische benadering gebruikt, wat inhoudt dat er verschillende soorten methoden, drie in dit geval, worden toegepast om alle kosten in kaart te brengen: de methode voor menselijk kapitaal (productieverlies), de WTP-methode (immateriële kosten) en de restitutiekostenmethode (medische kosten, voertuigschade en administratieve kosten). Inputgegevens werden opgehaald uit bestaande databases van verschillende partijen op het gebied van verkeersveiligheid en andere organisaties. Er werd een enquête onder huishoudens gehouden om aanvullende informatie te verzamelen, waaronder gegevens over medische behandeling, autoschade en politieaanwezigheid op de plaats van het ongeval. Om de immateriële kosten te schatten, bevatte de enquête ook vragen over de bereidheid van mensen om te betalen voor vermindering van het risico op dodelijke ongevallen. Er werd een vragenlijst (contingente waarderingsmethode) gebruikt met twee keuzescenario's: een keuze tussen twee routes en tussen twee steden, beide met een verschillend risico op dodelijke verkeersongevallen. Resterende gegevenslacunes zijn opgevuld door gebruik te maken van gegevens uit andere landen.

In deze casestudie worden de maatschappelijke kosten van verkeersongevallen in Kazachstan geschat op 6,8 miljard USD in 2012, wat overeenkomt met 3,3% van het BBP. Dit moet als een ondergrens worden beschouwd, omdat het aantal verkeersslachtoffers conservatief is geschat. Immateriële kosten vertegenwoordigen 81% van de totale kosten, voertuigschade 11% en productieverlies 6%. Administratieve en medische kosten zijn relatief zeer kleine kostencomponenten. Meer dan de helft van de kosten is gerelateerd aan verkeersgewonden, terwijl verkeersdoden ongeveer een derde van de totale kosten met zich meebrengen en materiële schade ongeveer 10% van de kosten. De kosten van een verkeersdode worden geschat op 764.000 USD, de kosten van een ernstig en licht gewonde op respectievelijk 101.000 USD en 8.000 USD en de kosten van een UMD-ongeval op 12.000 USD (prijzen 2012).

De casestudy geeft aan dat de kosten van verkeersongevallen in lage- en middeninkomenslanden waarschijnlijk aan de bovenkant liggen van de kostenramingen (uitgedrukt als percentage van het BBP) die in hoofdstuk 2 en 3 zijn gevonden, als alle belangrijke kostencomponenten worden meegenomen en geschat met behulp van de meest geschikte waardebepalingsmethoden. Dit is gerelateerd aan het relatief hoge aantal verkeersslachtoffers in deze landen, wat blijkt uit de hoge mortaliteit.

Monetaire waardering van het voorkomen van verkeersgewonden

In hoofdstuk 5 worden WTP-methoden voor monetaire waardering van het voorkomen van verkeersgewonden besproken en kritisch beoordeeld. Op basis van een literatuurstudie worden acht verschillende WTP-methoden voor monetaire waardering van het voorkomen van verkeersgewonden geïdentificeerd. Ze worden ingedeeld in drie groepen: directe WTP-methoden, indirecte WTP-methoden en de QALY-methode (Quality Adjusted Life Years). Directe WTP-methoden verkrijgen de WTP voor het verminderen van het risico om gewond te raken bij een verkeersongeval op een directe manier met behulp van ‘stated´ of ´revealed’ preference-methoden (gestelde of gebleken voorkeuren), terwijl indirecte methoden de WTP voor het verminderen van letselrisico bepalen ten opzichte van de WTP voor vermindering van dodelijk risico. De QALY-methode maakt gebruik van schattingen van het verlies aan levenskwaliteit en de monetaire waarde van een QALY.

De geschiktheid van WTP-methoden wordt beoordeeld aan de hand van vijf criteria: theoretische basis, betrouwbaarheid, het vermogen om te gaan met letseldiversiteit, bruikbaarheid en ethische kwesties. Op basis van deze criteria blijkt dat ‘stated choice’ (SC), een directe WTP-methode, de voorkeur geniet. In SC-enquêtes wordt respondenten gevraagd een keuze te maken tussen verschillende situaties (meestal reisroutes), die verschillen op het vlak van veiligheid, kosten en andere kenmerken zoals reistijd. SC is geworteld in de ‘random utility theory’ en heeft een sterkere theoretische basis dan de meeste andere methoden. Door de focus op afwegingen die individuen maken, is SC minder gevoelig voor verschillende soorten ´bias´ (bijvoorbeeld gerelateerd aan de opzet van de enquête) dan andere stated preference-methoden. Bovendien wordt SC minder geassocieerd met ethische bezwaren, omdat het gegevens gebruikt over keuzes die mensen in de praktijk maken in plaats van mensen op een directere manier te vragen hoeveel ze bereid zijn te betalen voor het voorkomen van letsel. Vergeleken met ‘revealed preference’ methoden heeft SC (evenals andere stated preference methoden) het voordeel dat de methode niet afhankelijk is van de beschikbaarheid van gegevens over werkelijk gedrag.

Een belangrijke beperking van SC is het feit dat slechts enkele soorten letsels kunnen worden beoordeeld en in geld uitgedrukt. De QALY-methode is de enige methode die in staat is om een waarde af te leiden voor een groot aantal types letsel en letselernst. Het combineren van SC en QALY's kan een veelbelovende richting zijn voor toekomstig onderzoek. Door SC en de QALY-methode te combineren, worden de sterke punten van beide benaderingen samengevoegd en deze gecombineerde aanpak zou gedetailleerde monetaire waarden voor het voorkomen van verkeersgewonden kunnen opleveren met een sterke theoretische basis.

Het aantal WTP-studies naar monetaire waardering van het voorkomen van verkeersgewonden is klein: er werden slechts dertien studies gevonden en in het literatuuroverzicht opgenomen. Hoewel de waarden van een vermeden ernstig gewonde in deze studies zeer uiteenlopen, van 1% tot 48% van de waarde van een statistisch mensenleven, geeft de literatuur aan dat het voorkomen van ernstig verkeersgewonden vanuit het perspectief van maatschappelijke welvaart minstens even relevant is als het voorkomen van verkeersdoden.

Verkeersgewonden in kosten-batenanalyse van verkeersveiligheidsmaatregelen

Hoofdstuk 6 presenteert een methodiek om de baten van het voorkomen van verkeersgewonden in KBA's op te nemen. De methodiek bevat twee nieuwe elementen ten opzichte van de standaard KBA-methode op het gebied van verkeersveiligheid. De standaard KBA neemt verkeersgewonden mee op een sterk geaggregeerd niveau, waarbij (hooguit) onderscheid wordt gemaakt tussen ernstig en licht gewonden zonder het type letsel te specificeren. Het eerste nieuwe element is een gedetailleerde classificatie van letseltypes en letselernst, gebaseerd op de EUROCOST-letselclassificatie van 39 letselgroepen en de Abbreviated Injury Scale (AIS). De vermindering van letsel(ernst) wordt vertaald in een toename van levenskwaliteit (Quality Adjujsted Life Years, QALY's) en in monetaire baten met behulp van een monetaire waarde per QALY. Ten tweede wordt er een koppeling gemaakt met ´human body model´ (HBM) simulaties. Simulaties van de impact van een botsing op het menselijk lichaam en de daaruit voortvloeiende veranderingen in de kans op letsel worden toegepast om de veiligheidsbaten te bepalen. Het integreren van HBM-resultaten in KBA's blijkt een efficiënte manier te zijn om de vereiste gedetailleerde informatie te verkrijgen over de effecten van veiligheidsinterventies, waarvoor (nog) geen gegevens uit de praktijk beschikbaar zijn.

De methodiek wordt toegepast in drie casestudies: een actieve hoofdsteun gericht op het verminderen van whiplash-gerelateerde aandoeningen; autonome noodremsystemen gericht op het voorkomen van botsingen tussen auto's en voetgangers en fietsers; en een verbeterde voorkant van trams gericht op het verminderen van de letselernst bij botsingen tussen trams en voetgangers. Gestandaardiseerde gegevens, waaronder ‘disabiity weights’ (wegingsfactoren voor effecten van letsel op kwaliteit van leven), het aandeel van letsels die levenslange gezondheidsgevolgen hebben, en monetaire waarden worden onder andere gebruikt om de output van HBM's te vertalen naar QALY's en monetaire baten. De casestudies illustreren de toegevoegde waarde van de methodiek voor een meer gedetailleerde en nauwkeurige bepaling van de specifieke veiligheidsbaten van voertuigveiligheidssystemen. Ze tonen aan dat de standaard KBA-benadering de baten van de preventie van verkeersgewonden aanzienlijk zou onder- of overschatten. Bovendien laten de casestudy's zien dat de beperkte beschikbaarheid van specifieke gegevens per casus over ongevalsrisico’s en kosten van veiligheidssystemen een belangrijke uitdaging vormt voor de kosten-batenanalyse van voertuigveiligheidssystemen.

Resultaten onderzoeksvragen

Hoofdstuk 7 bespreekt de antwoorden op de onderzoeksvragen die in dit proefschrift aan de orde zijn gesteld, alsmede de conclusies en aanbevelingen voor onderzoek en beleid op het gebied van verkeersveiligheid.

1. *Welke methoden worden in afzonderlijke landen toegepast om de welvaartseffecten (of maatschappelijke kosten) van verkeersongevallen te beoordelen?*

In de literatuur zijn drie belangrijke waarderingsmethoden beschikbaar om de maatschappelijke kosten van verkeersongevallen in te schatten: de restitutiekostenmethode, de ‘human capital’ methode) en de ‘willingness to pay’ (WTP) methode). Ze zijn gericht op de economische waardering van verschillende welvaartseffecten en daarom is een combinatie van de drie methoden nodig om alle maatschappelijke kosten in kaart te brengen. De restitutiekostenmethode wordt algemeen toegepast om medische kosten, schade aan eigendommen en administratieve kosten te berekenen, terwijl de human capital-methode wordt gebruikt om productieverlies te berekenen. Een meerderheid van de landen gebruikt echter niet de WTP-methode. Dit is een belangrijke omissie in de kostenramingen van verkeersongevallen in deze landen, waardoor de kosten aanzienlijk worden onderschat.

Er werden geen grote verschillen tussen landen gevonden wat betreft de belangrijkste kostencomponenten die in kostenstudies zijn opgenomen, maar er werden wel verschillen gevonden op een meer gedetailleerd niveau (binnen de belangrijkste componenten). Vermijdingskosten, die voortvloeien uit het aanpassen van reisgedrag vanwege (perceptie van) veiligheidsniveaus, is een belangrijke ontbrekende kostenpost in kostenbeoordelingen van verkeersongevallen.

2. *Hoe groot zijn de welvaartseffecten in afzonderlijke landen en wat is de uitsplitsing ervan naar letselernst en kostenposten?*

De welvaartseffecten van verkeersongevallen (of de maatschappelijke kosten van verkeersongevallen) worden geschat op het equivalent van 0,4 tot 6,0% van het bruto binnenlands product (BBP) in individuele landen. De grote variatie tussen landen wordt voornamelijk verklaard door de verschillen in de gebruikte methoden om de kosten te schatten, met name het al dan niet meenemen van WTP-waarden. De casestudie in Kazachstan, waar de kosten conservatief werden geschat op het equivalent van 3,3% van het BBP, geeft aan dat de kosten van verkeersongevallen in lage- en middeninkomenslanden waarschijnlijk aan de bovenkant van de bandbreedte liggen, gegeven het relatief hoge aantal verkeersslachtoffers in veel van deze landen en het feit dat door conservatieve aannamen de kosten waarschijnlijk nog zijn onderschat.

Verkeersgewonden hebben een groot aandeel in de maatschappelijke kosten van verkeersongevallen, gemiddeld ongeveer 50% van de totale kosten, hoewel de verdeling van de kosten over de categorieën van letselernst per land aanzienlijk verschilt. De kosten van verkeersgewonden zijn (veel) hoger dan de kosten van verkeersdoden en van UMS-ongevallen. Immateriële kosten hebben een groot aandeel in de totale kosten van verkeersongevallen, meestal meer dan 50% van de totale kosten, vooral als ze gebaseerd zijn op de WTP-methode. Andere relatief grote kostenposten zijn materiële schade en productieverlies. Medische kosten en administratieve kosten zijn relatief gering.

3. *Wat is/zijn de meest geschikte methode(n) om de monetaire waarde van het voorkomen van verkeersgewonden te schatten?*

Uit de beoordeling van acht WTP-methoden blijkt ‘stated choice’ (SC) de voorkeursmethode te zijn voor monetaire waardering van de preventie van verkeersgewonden, vooral vanwege de theoretische grondslag en de betrouwbaarheid. Een belangrijke beperking van deze methode is het feit dat SC slechts een paar soorten letsels kan meenemen. Alleen de QALY-methode is in staat om een waarde toe te kennen aan een groot aantal types letsel en letselernst. Daarom is het combineren van SC en de QALY-methode een veelbelovende richting voor toekomstig onderzoek.

De meest geschikte methoden om de medische kosten en het productieverlies als gevolg van verkeersletsel te berekenen zijn respectievelijk de restitutiekosten- en de human capital methode (zie hierboven). Deze methoden worden algemeen toegepast en zijn relatief onomstreden.

4. *Hoe kan de schatting van de baten van het voorkomen van verkeersgewonden in kosten-batenanalyses (KBA's) nauwkeuriger worden gemaakt en rekening houden met effecten op specifieke soorten letsel en letselernst?*

Gedetailleerde letselclassificatie en categorieën van letselernst, zoals de EUROCOST-letselclassificatie en de AIS zoals toegepast in dit proefschrift, kunnen in combinatie met QALY's worden gebruikt om de baten van het voorkomen van verkeersgewonden nauwkeuriger te schatten. De resultaten van HBM-simulaties zijn een nuttige bron voor gegevens over de effecten van verkeersveiligheidsmaatregelen op specifieke letsels en op de ernst ervan, die nodig zijn voor deze gedesaggregeerde aanpak. Aangezien de standaard KBA geen rekening houdt met het type letsel en de ernst ervan (anders dan licht versus ernstig letsel), verbetert deze nieuwe aanpak de nauwkeurigheid van KBA's van verkeersveiligheidsmaatregelen aanzienlijk, vooral als ze (zoals verschillende voertuigveiligheidssystemen) gericht zijn op het voorkomen van specifieke soorten letsel of op het verminderen van de ernst van letsel.

Conclusies en de gevolgen voor beleid en verder onderzoek

1. *Schattingen van het effect van verkeersongevallen op de welvaart vertonen een grote variatie tussen landen, die voornamelijk wordt verklaard door methodologische verschillen.*

Het belangrijkste methodologische verschil is het al dan niet toepassen van een WTP-methode om de immateriële kosten te schatten. Dit heeft een aanzienlijke invloed op de geschatte maatschappelijke kosten, aangezien WTP-waarden veel hoger zijn dan waarden op basis van andere methoden. Verder zijn er verschillen met betrekking tot de kostenposten die worden meegenomen in studies naar de welvaartseffecten van verkeersongevallen.

Deze conclusie impliceert dat internationale harmonisatie van methoden nodig is om de maatschappelijke kosten te gebruiken als internationale beleidsindicator. Het ontwikkelen van nieuwe internationale richtlijnen voor het schatten van de maatschappelijke kosten van verkeersongevallen wordt aanbevolen als een eerste stap op weg naar harmonisatie. Deze richtlijnen zouden onder andere moeten aangeven welke kostenposten moeten worden meegenomen en welke methoden moeten worden toegepast om elke kostenpost te schatten.

2. *In veel landen worden de welvaartseffecten van verkeersongevallen onderschat door methodologische tekortkomingen.*

De welvaartseffecten van verkeersongevallen worden onderschat doordat WTP-waarden niet worden meegenomen, onderregistratie van het aantal slachtoffers en ongevallen niet (goed) wordt meegenomen en/of een schatting van de kosten UMS-ongevallen ontbreekt. Aanbevolen wordt om deze tekortkomingen aan te pakken door:

- WTP-onderzoeken uit te voeren in meer landen of WTP-waarden uit andere landen te gebruiken ('value transfer');
- de kwaliteit en representativiteit van statistieken over verkeersveiligheid te verbeteren door de procedures voor het verzamelen van ongevals- en slachtoffergegevens te verbeteren en gegevens uit verschillende bronnen te koppelen, en/of internationale onderzoeksresultaten over onderregistratie in kostenstudies te gebruiken;
- schattingen van de kosten van UMS-ongevallen op te nemen in kostenstudies, bijvoorbeeld door enquêtes te houden over de betrokkenheid van mensen bij UMS-ongevallen en de bijbehorende kosten, of gegevens over deze kosten uit andere landen te gebruiken;
- gevoeligheidsanalyses op te nemen in kostenstudies om onzekerheden in de invoergegevens mee te nemen.

3. *Verkeersongevallen leiden tot een groot verlies van maatschappelijke welvaart.*

In de meeste landen, met name lage- en middeninkomenslanden, liggen de welvaartseffecten van verkeersongevallen waarschijnlijk aan de bovenkant van de bandbreedte die in dit proefschrift is gevonden (het equivalent van 0,4 tot 6,0% van het BBP) of zelfs hoger, gezien de methodologische tekortkomingen en de daaruit voortvloeiende onderschatting van de kosten. Dit wordt bevestigd door de casestudy in Kazachstan, waar de welvaartseffecten conservatief worden geschat op het equivalent van 3,3% van het BBP.

Deze conclusie impliceert dat effectieve investeringen in verkeersveiligheid grote kostenbesparingen kunnen opleveren, wat beleidsmakers een extra stimulans kan geven om te investeren in het verbeteren van de verkeersveiligheid. Het inzicht in de maatschappelijke en economische impact van verkeersongevallen kan worden vergroot door in toekomstig onderzoek andere perspectieven te hanteren. Hierbij kan worden gedacht aan de impact op de economie, zoals gemeten aan de hand van (bijvoorbeeld) het BBP per hoofd van de bevolking, en de verdeling van de kosten over belanghebbenden. Het meenemen van verdelingseffecten in KBA's, bijvoorbeeld een kleine toename van het aantal verkeersslachtoffers versus een (kleine) reistijdbesparing voor een groot aantal weggebruikers, wordt ook aanbevolen voor toekomstig onderzoek.

4. *Verkeersgewonden zijn verantwoordelijk voor een groot deel van de welvaartseffecten van verkeersongevallen, maar er wordt onvoldoende aandacht aan besteed bij economische analyse van verkeersveiligheid.*

Het aantal studies naar de monetaire waardering van het voorkomen van verkeersgewonden is zeer beperkt, hoewel de welvaartseffecten van verkeersgewonden veel groter zijn dan die van verkeersdoden. Bovendien worden verkeersgewonden alleen op een sterk geaggregeerd niveau meegenomen in KBA's, zonder dat er voldoende rekening wordt gehouden met het specifieke type letsel en de effecten op de ernst van het letsel.

De hoge welvaartslast rechtvaardigt meer beleidsaandacht voor verkeersgewonden, bijvoorbeeld door in meer landen nationale doelen te stellen voor het terugdringen van het aantal verkeersgewonden. Verder wordt aanbevolen om meer onderzoek te doen naar de monetaire waardering van het voorkomen van verkeersgewonden, bij voorkeur met behulp van een combinatie van de stated choice-methode en QALY's. Dit zal bijdragen aan een betere leidraad voor de waarden die gebruikt moeten worden bij de berekening van de maatschappelijke kosten van verkeersongevallen en in KBA's.

Het wordt aanbevolen om de nieuwe KBA-methodologie met de gedetailleerde classificatie van verkeersletsel, die is gepresenteerd in dit proefschrift, verder te ontwikkelen en toe te passen. Gebieden die voor verbetering vatbaar zijn, zijn onder andere een verdere analyse van de impact van de vermindering van de letselernst op de levenskwaliteit (met behulp van ‘disability weights’) en een verbetering van de schattingen van het ongevalsrisico, bijvoorbeeld door gebruik te maken van verzekeringsstatistieken.

Dankwoord

Wie schrijft, die blijft. Dit gezegde verwoordt goed waarom ik, alweer een flink aantal jaren geleden, wetenschappelijke artikelen ging schrijven. Ik wilde graag de resultaten van mijn onderzoek delen met anderen in mijn vakgebied en vastleggen in publicaties met een wat langere houdbaarheidsdatum dan 'gewone' onderzoeksrapporten. Na een paar artikelen realiseerde ik mij dat ik onbewust al een eind op weg was met het schrijven van een proefschrift. Daarvoor moest ik nog wel een aantal extra stappen zetten, maar de keuze om toch echt ´een boekje´ te gaan schrijven was uiteindelijk vrij snel gemaakt. Dat het nu ook echt gelukt is voelt nog steeds wat onrealistisch, maar geeft ook veel voldoening.

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About the author

Wim Wijnen was born in Zuidlaren on July 8th in 1974. He went to the Willem Lodewijk Gymnasium in Groningen, where he obtained his diploma in 1993. He studied Economics at the Rijksuniversiteit Groningen. During an internship at the Agricultural Economics Institute, he wrote his master thesis entitled ‘Welfare economic analysis of changes in rural areas’. After graduating in 1999, he went on to work as a researcher and project manager at the Agricultural Economics Institute (1999-2002) and at TNO (2002-2004).

From 2004 to 2012 Wim worked at the Institute for Road Safety Research (SWOV), where he specialised in the economics of road safety. In 2012 he started working as an independent researcher and consultant and founded his company ‘W2Economics’. His work concentrates on economic analysis of road safety, such as the social costs of road crashes, monetary valuation of preventing road casualties and cost-benefit analysis of road safety measures. He conducted projects for international organisations, national governmental bodies and NGOs, universities, road safety research institutes and companies in many countries, including several low- and middle-income countries. He has presented his work at conferences and workshops worldwide and he is also a guest lecturer at universities.

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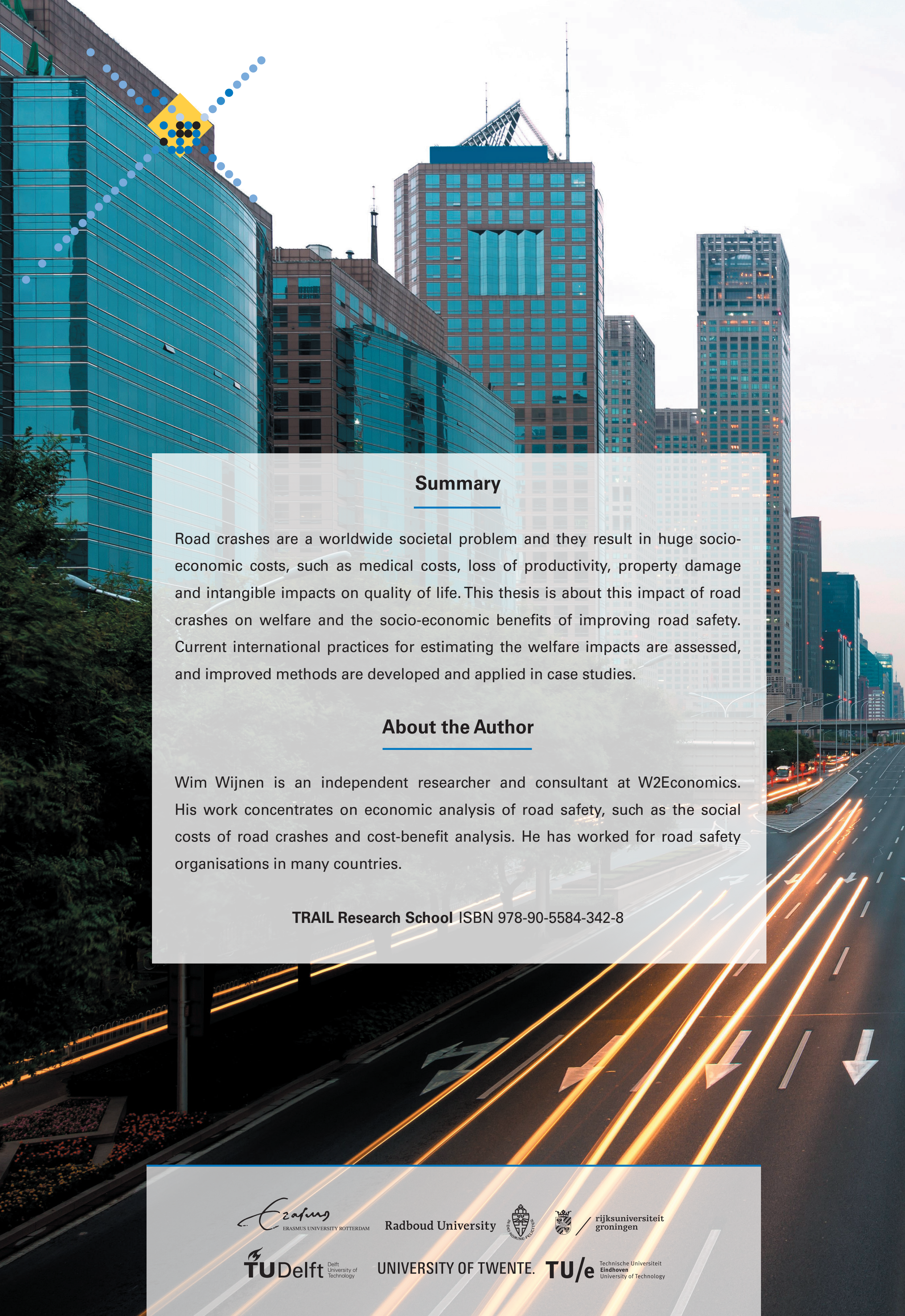

Summary

Road crashes are a worldwide societal problem and they result in huge socio-economic costs, such as medical costs, loss of productivity, property damage and intangible impacts on quality of life. This thesis is about this impact of road crashes on welfare and the socio-economic benefits of improving road safety. Current international practices for estimating the welfare impacts are assessed, and improved methods are developed and applied in case studies.

About the Author

Wim Wijnen is an independent researcher and consultant at W2Economics. His work concentrates on economic analysis of road safety, such as the social costs of road crashes and cost-benefit analysis. He has worked for road safety organisations in many countries.

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